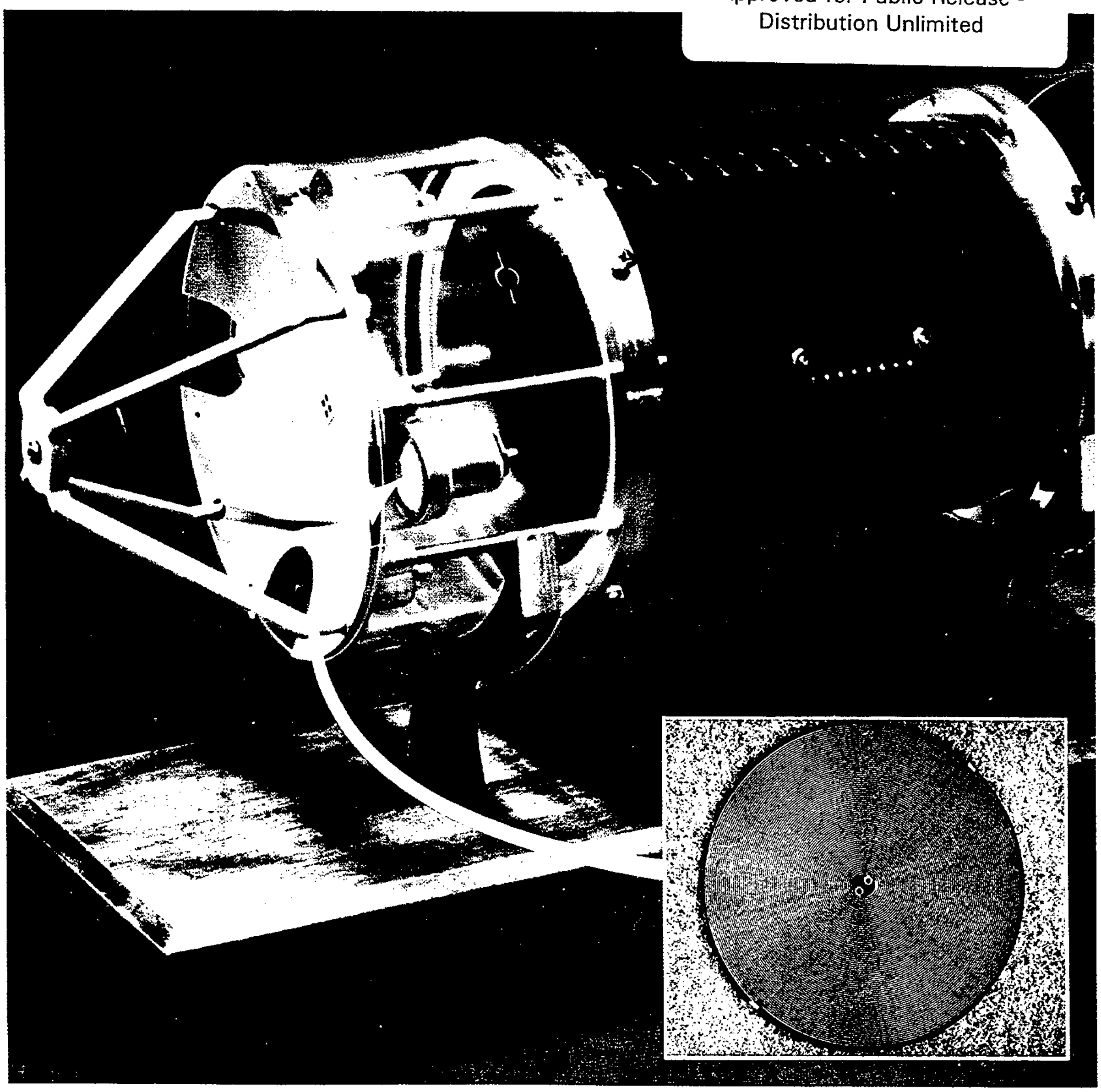
US Army

ManTech Journal

Implementing New Technologies

Volume 9/Number 1/1984



USArmy
ManTechJournal

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About the Cover

An inexpensive non-planar printed circuit board component for radar guided missiles is shown in this cover photograph. Developed by General Dynamics (Pomona) for the U.S. Army Missile Command, the objective of achieving a new fabrication technique for a highly accurate antenna configuration was met by use of a highly stable injection molded polymer reflector. The reflective surface is accurate to 1/100 of a wavelength, despite the unit's inexpensive manufacture.

THE MANTECH JOURNAL is prepared quarterly for the U.S. Army under the sponsorship of the Directorate for Manufacturing Technology, DARCOM, by the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172, through the Metals and Ceramics Information Center, Battelle's Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

SUBSCRIPTION RATES: Individual subscriptions to the ManTech Journal are available through the Metals and Ceramics Information Center of Battelle. Domestic: $50.00–one year. Foreign: $100.00 per year. Single Copies: $13.00.

Comments by the Editor


RAYMOND L. FARROW

The coming year promises to focus attention on our efforts in manufacturing technology as never before, as efficiency in production becomes an ever more important factor toward meeting our objectives in the production of military items. The current adjustments in administration of the DOD manufacturing technology program will have numerous impacts on the services' projects and undoubtedly will give rise to some degree of uncertainty for some individual projects, but in the long term our efforts will receive many benefits from the increased attention given by those responsible in government, and, also, by the public. One of the more significant of these items that soon will be in operation is the proposed Manufacturing Technology Information Analysis Center, which will be discussed in more detail in a later issue of the U.S. Army ManTech Journal.

This issue of the Journal features some highly significant developments that have resulted from successful Army mantech projects. Non-planar PC board fabrication fits nicely into that category, as described in our first lead article and illustrated on our front cover. The project goal to produce an inexpensive non-planar PC board component for airborne radar guidance of missiles met with remarkable success. The ultimate device developed from the program is a model of efficiency—a self-contained transmitter/receiver which operates with extreme accuracy under tough environments, providing the functional capability required. The cost of the item was kept down thru a well conceived and managed project, and is a prime example of what Army mantech projects can achieve.

Our second featured article on compliant air bearing gyros also represents an outstanding mantech achievement. A 24 percent reduction in projected production cost of the component was all the more remarkable, since a sharp change of direction in the approach of the program was required as new data were developed. Insurmountable technical difficulties mandating the change nevertheless did not prevent the successful development of new manufacturing techniques that brought significant cost reductions. Also, the technical credibility of the item's operational performance was firmly established.

The production rate of infrared detectors of laser energy for laser warning receivers was increased through the successful completion of an Army project that developed a manufacturing technology which would produce the components at a rate of 50 per 40-hour week. In the course of this program, a determination was required as to which type of device structure would be most feasible for a higher production rate. The mesa type that ultimately was selected experienced a pilot run on a new facility designed expressly for this increased production rate, providing the feasibility of the technology under a production environment. Original production rate goals were exceeded by a factor of 6.5, attaining an overall yield of 32.7 percent.

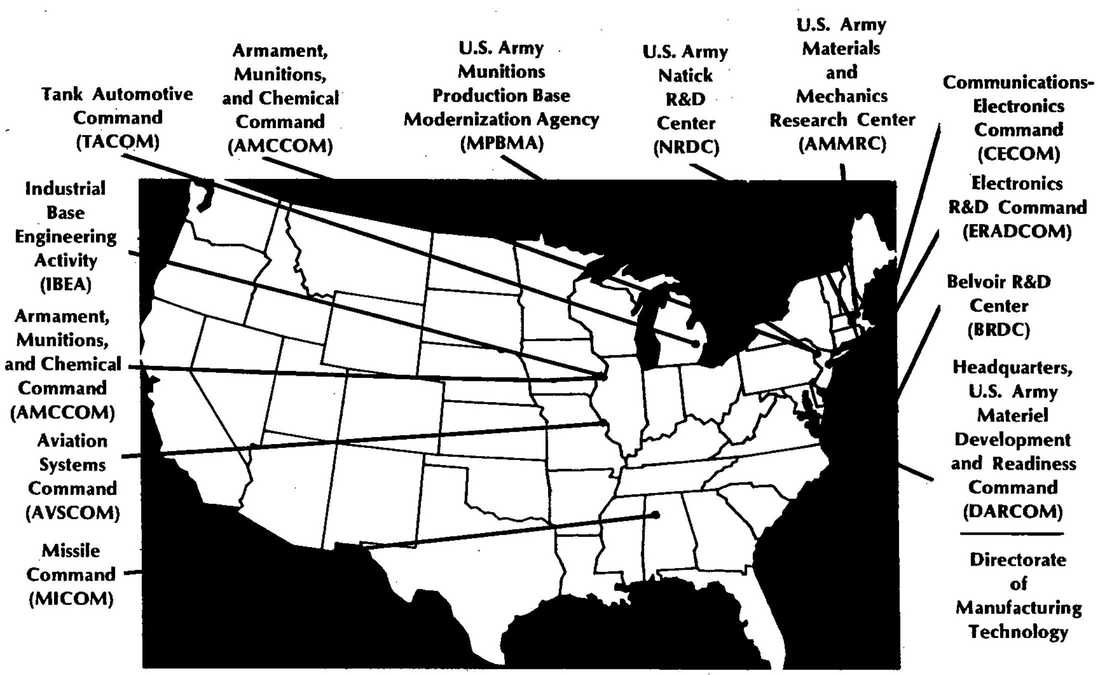
The excessive physical size and sheer complexity of large scale hybrid microelectronic items has caused severe manufacturing problems, but this was dramatically improved by the Army mantech project described on page 25 of this issue. The high frequency of rework that always has been required by the fabrication of such complex items was sharply reduced as a result

of this program. A new technology featuring the use of bumped tape automatically bonded beams made possible a fabrication technique that led to the successful attainment of project goals.

Ultrasonic activation of cutting tools met with considerable success in another Army mantech project that enabled the manufacturer to increase removal rates of machined items as much as 700 percent on materials that historically have presented difficult machining problems. With the ultrasonic assist, not only were metal removal rates increased, but tool wear and breakage were also reduced. This remarkable development will have a strong impact in years to come in projects where designers might otherwise have been reticent to specify a material that would have had the required performance characteristics, but which would present costly fabrication problems.

Six pages of brief status reports on ongoing Army mantech projects present a summary of efforts being undertaken by the major Army commodity commands. Each of these briefs lists the name and telephone number of the point of contact for that particular topic, so that readers can simply call him and obtain more complete information about the new technology as it is being developed. This custom has brought a lively exchange of information among industry and service personnel charged with improving our production capability.

DARCOM Manufacturing Methods and Technology Community



New Technique Accurate, Inexpensive

Non-Planar PC Board Fabrication Meets Specs

ROBERT L. BROWN is a General Engineer at the U.S. Army Missile Command in Huntsville, Alabama. His current projects involve creative direction of contractor engineers on projects such as the fully additive manufacture of printed wiring boards (Hughes), ultraviolet curing of conformal coatings for PC boards (Hughes), product cleanliness techniques for PC boards (Martin-Marietta), laser scan testing of PC boards (Chrysler), rigidflex assemblies (McDonnell-Douglas), and insertion of nonaxial lead devices in locaserts (Martin-Marietta), a recent approved success. A Registered Professional Engineer in Alabama and holder of a B.S. in Metallurgy (1958) from Alabama University, Mr. Brown holds six patents and is author of fifteen technical briefs which NASA rates as equivalencies to patents. He was the first recipient of the NASA "Noteworthy Contribution" award in 1970 for his many contributions to their technical utilization program, and patented several inventions that were used in production.

Formidable dimensional specifications were exceeded and a new manufacturing technology brought additional cost savings from an MM&T project recently completed for the U.S. Army Missile Command. Conducted by the Pomona Division of General Dynamics, the project goal was to produce an inexpensive non-planar printed circuit board component for radar guided missiles. The device was designed to be a self-contained transmitter/receiver to fit into the nose of a missile and operate under severe g-loads, providing extremely accurate and reliable targeting.

The objectives of the project concept were to develop new manufacturing technology for the fabrication of an antenna configuration that would provide accurate missile guidance, yet offer relatively low cost. The key to achievement of this goal was the development of a highly stable injection molded polymer reflector with a reflective surface accurate to 1/100 of a wavelength and additively plated to a minimum of .001 inch.

Two Tasks Undertaken

The effort encompassed two tasks: Task I addressed the manufacturing methods and applied technologies to produce a cassegrain antenna system designed to operate at 94 GHz. The antenna configuration analysis was completed and material selection criteria established. Design criteria and measured data were developed on three versions of broad-band spiral antennas.

The additive plating of the reflective surfaces was considered, as was the pattern generation of the subreflector grid. Test results also showed successful generation of the subreflector grid pattern to the required dimensions.

Task 2 addressed the manufacturing methods and technology required to produce an eight-layer cylindrical circuit board.

Material selection criteria were established, as were the requirements and technique of pattern generation and alignment. The forming process and related tooling were selected and the semi-additive process for installing plated-through holes was developed, as were data showing plated-through hole integrity and circuit continuity.

The work was performed by the Advanced Manufacturing Technology Department of the Pomona Division of General Dynamics Corporation under the technical cognizance of the United States Army Missile Command, Redstone Arsenal, Alabama.

NOTE: This manufacturing technology project that was conducted by General Dynamics' Pomona Division was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Robert Brown, (205) 876-5321.

The antenna system was comprised of a parabolic main reflector approximately 6 inches in diameter, a hyperbolic subreflector, a four port feed, and four 1-inch-diameter broad band spiral antennas with related cavity backing and feed connections. Materials, processes, and manufacturing technology required to produce an 8 layer, multilayer cylindrically shaped circuit board assembly having a minimum inside diameter of 5 inches were also determined.

Antenna Design Features

Discrete 1-inch diameter spirals were formed on the surface of the primary antenna dish sufficiently close to the edge as to be unobstructed by the subreflector. Each spiral was loaded with a cavity for operation in the 2.75 to 18 GHz range.

The subreflector had a curvature designed to feed the incoming radiation into the 4-port feed at the center of the primary reflector with minimum aperture blockage. Both the primary and secondary reflectors had a curvature that replicates the calculated curve to approximately 1/100 of a wavelength and were free from defects.

The secondary mirror had its 1-mil-thick reflecting surface divided into a grid of reflecting metal squares. Each square was one quarter of a wavelength on a side for a frequency of 94 GHz. The tolerance on the squares was about .001 inch, with a spacing of approximately .003 inch between edges of adjacent squares. The entire antenna assembly was mounted to an aluminum ring to simulate the forward end of a 6-inch diameter missile and was of a quality to serve as a bench test prototype.

The antenna configuration described is shown in Figure 1. The analysis of the antenna geometry is as follows:

D_M	=	Diameter of main Reflector
D_S	=	Diameter of subreflector
RFP	=	Real Focal Point
VFP	=	Virtual Focal Point
Θ_R	=	Angle (see Figure 1)
Θ_V	=	Angle (see Figure 1)
F_c	=	Distance from RFP to VFP
F_m	=	Distance from Dm (apex) to VFP
L_v	=	Distance from Ds (apex) to VFP

A computer program was formulated to perform the necessary computations.

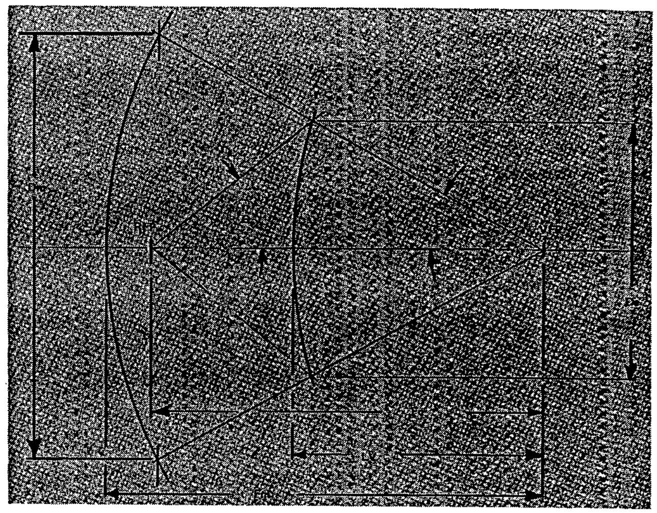


Figure 1

Materials Evaluated

A materials evaluation was conducted to enable selection of a material that would simultaneously fulfill the requirements specified for the manufacture of non-planar printed circuits.

Initially, a chart was prepared listing the significant properties of various candidate materials. A list of abbreviations for these materials is shown in Table 1. Considered were those properties and/or characteristics which were assessed to be of greater importance to the success of the project. Foremost among the material attributes were (1) platability; (2) formability, (3) thermal stability; (4) structural adequacy; (5) process repeatability; and (6) cost.

The more current polymers were listed as well as some standard plastics and composites. Included for comparison were properties for aluminum, brass, and steel.

Any material that was acceptable for use on the project had to be platable by semi-additive processing. Therefore, any

TABLE 1. LIST OF ABBREVIATIONS

Abbreviation	Chemical Name
PPS	Polyphenylene sulfide
PEI	Polyether-imide
PAI	Polyamide-imide
PPO	Polyphenylene oxide
ABS	Acrylonitrile butadiene styrene
PBT	Polybutylene terephthalate
PVC	Polyvinyl chloride
Mindel	Polysulfone/ABS alloy

material that failed to meet the platability aspect was unacceptable for use in non-planar hardware.

In view of the foregoing evaluation, a decision was reached to apply the material Mindel A-650 to this application. Mindel is an alloy of ABS and Polysulfone. As such, it provides the superior plating attributes of ABS, with the higher thermal stability and strength properties of the Polysulfone.

It is also worth noting that the material PPO could also be fabricated and processed successfully with the same tooling. The same statement applies to the PEI (Ultem) material.

Detail Design Configuration

Incorporated into the body of the main reflector of the nonplanar antenna are the provisions for the four port square waveguide feed and the cavities in which the connectors, baluns, and feed wires connect to the broad band spirals. Provision is also included for the mounting of the features of the subreflector support structure and the subreflector. Figure 2 shows the main parabolic reflector detail.

Tooling was designed and fabricated to permit the injection molding of the main reflector and the subreflector. The gating features in the molds were tailored during the molding process so as to minimize sinks and provide for correct filling of the mold, replicating the desired surface finish on the molded part.

Tooling for the main reflector includes design features required for (1) proper heating of the mold, (2) gate sizing to insure complete fill of the mold during injection of the plastic, (3) good surface finish, and (4) freedom from undesired sinks in the reflector surface and spiral cavity feature.

Tooling for the subreflector likewise was designed to achieve proper fill, exhibit good surface finish, and prevent sinks in the reflector surface.

Spheroidal Measurement Difficult

Inspection of the non-planar antenna components proved more difficult than originally anticipated. A closer examination of the problem revealed that accurate results could not readily be obtained using conventional measuring techniques. The difficulty in obtaining accurate measurements occurred primarily on the topological curved surfaces even by using a validator, a device capable of measuring any object up to 4 feet x 4 feet x 3 feet to within 0.0005 inch.

The reason for this difficulty centered on the geometry of the measuring probe, which was used to establish the position of the topological curved surfaces relative to a fixed coordinate system.

A solution to the problem was to compensate for the geometry of the probe by actually determining the point of contact the probe made with the curved surface.

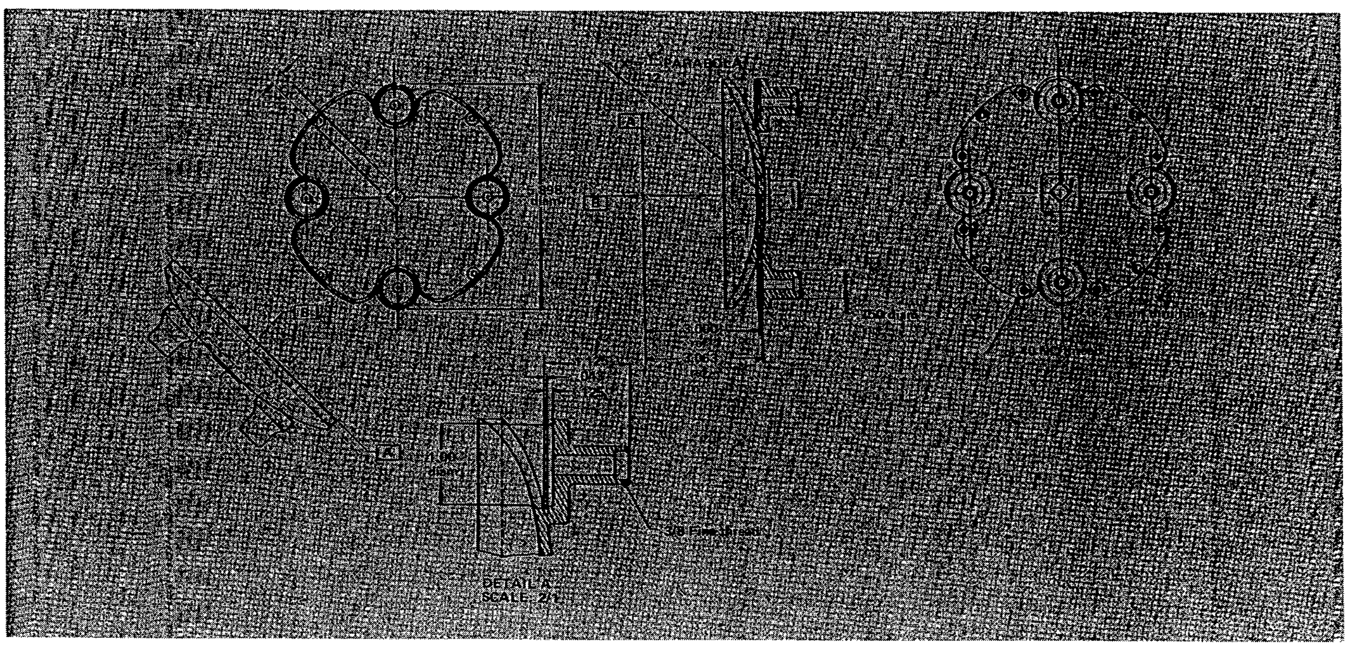


Figure 2

In this particular case, a probe with a spherical tip was used. The spherical tip was used to prevent damage of the parts or tools. However, the spherical tip probe affected the accuracy of the measurements made on the curve surface by the validator. This decrease in accuracy was due to the fact that all the measurements are referenced from the tip of the probe where contact with the measuring surface is assumed to occur.

This, however, is not what happens when measuring these curved surfaces. Contact may occur on the sides of the probe's spherical tip, depending where the probe is on the curved surface. In order to compensate for this problem a computer program was written that proved to be very laborious and time consuming. So an alternative method was found to measure the antenna parts and tools.

Solution Reached

This method involved the use of a computer-controlled three-dimensional measuring machine manufactured by Zeiss. The theoretical procedures used by the Zeiss machine check the topology of spatially curved surfaces using computer controlled 3-D measuring machines. Included among such surfaces are geometrically complex gears, thread profiles, impeller pump and turbine blades and wind tunnel or towing tank models. Modern computer numerically controlled coordinate measuring machines are now capable of making such measurements through rapid point-to-point scanning and computer analysis.

A mathematical representation of the nominal surface is generated and stored in a main frame computer and compared with the actual surface as measured by the coordinate measuring machine. Deviations between the two are illustrated graphically on an x-y recorder by superimposing the network of actual points on the nominal point network. Comparison of the actual surfaces before and after various types of processing permits analysis of the topological effects of such processing.

General Considerations

When checking the forms of spatially curved surfaces, the following requirements must be addressed:

- The nominal surface must be expressable as a mathematical model.
- The actual surface must be measureable with the required accuracy in a reasonable period of time.
- Quantitative comparison of the actual and nominal surfaces shall be possible.
- The causes of any deviations shall be interpretable to permit optimization of the manufacturing method.

While the measurement of geometrically simple bodies such as cylinders and cones is relatively easy, it becomes significantly more difficult in the case of three dimensional curved surfaces.

A flow chart covering the design, manufacture, and checking of compound curved surfaces is shown in Figure 3. Main frame computers permit simulation of complete manufacturing processes based on machine kinematics and tool geometry. These methods result in mathematically defined surfaces which can be compared with machined surfaces through the use of sophisticated, high speed coordinate measuring machines.

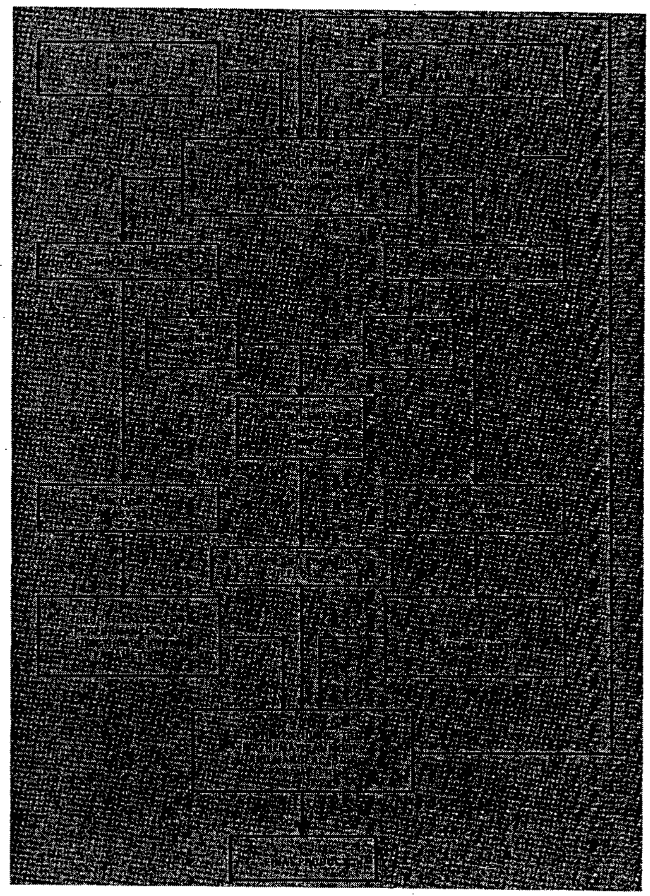


Figure 3

The Actual Measurement

When measuring compound curved surfaces the "continuous probing" mode of the Zeiss system is particularly beneficial—the machine can follow the contour of a part in a predetermin-

ed direction in the same manner as the follower head on a 3-D copy mill. The automatic positioning control which is actuated at probe contact scans the free axis of the machine until the inductive measuring system in the probe head is brought to its null point. The moment this condition is achieved all three machine coordinates are automatically transmitted to the computer. Thus, for instance, the probe may be locked in the X axis and be made to traverse to predetermined locations in the Y axis, while automatically following contour changes of the part in the Z axis; the machine will remain at a preselected X-Y location until the probe has been nulled in the Z direction and the position information transmitted to the computer. It will then proceed to the next X-Y location.

Quantitative relationships between setup variations and resulting form variations cannot be established without computer data processing. Analysis of measurement results must also be done by computer. The nominal surface is calculated by simulation of the manufacturing process. The input parameters for the calculation correspond to the setup parameters. This relationship is taken advantage of in analysis of the surface deviations. By introducing slightly changed machine setup parameters, the computer can generate variations of the original nominal flank, changing the form and location of the point network. An additional software routine in the main frame computer compares the desired nominal flank with the numerically altered flank and develops a list of deviations. The simulated errors then are compared with the measurement results and after several iterative steps the theoretical setup parameters responsible for generating the actual gear can be pinpointed and evaluated.

The absolute variation in the part tolerance is presented on the Zeiss readout sheet as Form Error. The Form Error is the absolute deviation about the theoretical curved surface. This means that for a form error of 0.00167 inch, the actual curve surface varies .0008 inch about the theoretical curve.

The Zeiss data indicated that the form errors of the paraboloid and hyperboloid curved surfaces were .0011 and .0008 respectively, within the specified tolerance, 0.0013 inch.

Spiral Antenna Design

The design of the spiral antennas required for this effort was undertaken initially using an equiangular logarithmic spiral approach. Using the one-inch diameter specified and establishing that a two arm spiral would be used in the application, the feed point dimensions were set at .050 inch. With these features defined, the equation of the equiangular spiral was written. This equation was used in the computer program to generate the coordinates of the spiral geometry. The coordinates thus obtained were then used to enable the generation of art masters via computer aided design using a photo plotter.

The artwork was applied to additively plated polysulfone substrates and the spiral pattern etched in the metallization to produce a functional circuit board. Additional details required for the assembly of a functional antenna were fabricated, permitting the functional evaluation of the broad band spiral antenna.

Subreflector Grid Artwork Generation

The artwork pattern formation for printing the hyperbolic subreflectors was initiated in the computer aided design group and recorded on magnetic tape. The information stored on the tape was the precise dimensions of the grid and grid spacing (0.0314 inch square by 0.003 inch space). This magnetic tape was sent to the Electromask Microphotography Facility for final processing on the Series 2500 Pattern Generator/Image Repeater. This device uses laser light for exposing a light sensitive polymer. The polymer is developed in a chlorinated hydrocarbon solvent and then etched in sulfuric acid yielding the desired pattern. The residual polymer is stripped in acetone and inspected for dimensional accuracy.

Cost Comparison of Alternate Methods

Several manufacturing processes were studied before injection molding was selected. Low cost dictated the method used in the development of these parts. Labor intensity is an excellent criteria for cost if the raw materials are not expensive and have similar values.

The manufacturing processes studied were:

- Injection Molding
- Precision Casting
- Machining
- Electro-Forming.

Each of these processes are evaluated as though they are being made in production. The tooling cost for injection molding, precision casting and electro-forming would be similar. The tooling cost for NC machining would be less, but only by about one half.

Task 2 Requirements

The cylindrical printed wiring board was to be nominally five inches in inside diameter and 6 inches long. The eight-layer cylindrical circuit board was to have a 1/2-inch square grid pattern of 10 mil wide copper circuits. All layers of the multilayer grid had pads at the intersection of the grid lines.

Drilled holes were plated through, well centered on all pads of each layer, and no larger than 0.042 inch diameter.

Materials and Process Evaluation

The basic intent of this program was to find a material/process system to produce military printed wiring boards having a cylindrical shape. This system was to have the highest poten-

tial of producing additive plated printed wiring boards to military test requirements. Although polyimide-acrylic material was recognized early as a prime candidate, other types of materials were evaluated during this phase to provide comparative data for the polyimide-acrylic materials.

Five potential constructions were evaluated to manufacture cylindrically curved single-sided, double-sided, and multilayer printed wiring boards. Extensive work was done to evaluate each processing step in the various constructions for complexity, cost, ease of manufacture, and potential for having a 95 percent confidence level.

(1) **Glass-reinforced polyimide supported copper-clad substrates** capable of being bonded with B-stage glass supported polyimide adhesive layers was the first construction to be evaluated. Here, the innermost pre-etched layer would be wrapped around a mandrel and bonded with a B-staged polyimide adhesive system. Subsequent pre-etched layers .007 inch thick would be registered with the first layer by the use of tooling pins and then bonded with adhesive layers. A unique bonding method was developed by General Dynamics Pomona several years ago to laminate composite wings and fins. This methodology is called elastomeric pressure bonding. A silicone potting resin is cast to a cylindrical shape and placed against the layers to be bonded. The layers and silicone form are restrained by the inner mandrel and outer box. The assembly is then placed in an oven at 350 F for 1 hour, causing the silicone rubber to expand and exert uniform pressure of 50 psi, thus allowing the B-staged polyimide adhesive to cure. Using this method for bonding eliminates the need for elaborate tooling and expensive presses.

(2) A similar approach was taken using **unreinforced polyimide supported copper-clad substrate** (Kapton by Dupont). These flexible layers were bonded using B-staged glass supported polyimide adhesive layers. By effectively removing half of the glass reinforcement, it was felt that conventional processing steps could be utilized. After processing, the laminate was wrapped around the mandrel. During this process the board delaminated and cracked due to the stiffness of the glass reinforcement. This approach was abandoned.

(3) An evaluation was made of **polysulfone copper-clad laminate samples.** The samples were pre-etched and thermoformed using heat and pressure over a mandrel. This system looked promising until we found that Norplex (sole source of polysulfone/Cu clad laminates) had decided that the market could not support their product and a production facility was never built.

(4) A fourth construction evaluated was the use of **injection molded polysulfone.** By utilizing injection molding techniques it is possible to eliminate the costly drilling step. Pins can be built into the mold to allow for "molded in holes". Expensive tooling would be required to injection mold the four individual components. Each layer would have to be additively plated, imaged, and etched in a cylindrical configuration. This processing sequence, very similar to that previously described in (1), is very complex, costly, and unreliable.

(5) The evaluation led us to the use of **all flexible materials** manufactured by Dupont. Flexible printed wiring for electrical interconnections has been an important production product for years. They have replaced mazes of "hard wiring" for assembly simplification, neatness, maintainability, and reliability, all of which are crucial in military electronics. Electronic circuit boards made by flexible polyimide are lower weight and require less space than the wiring systems which they have replaced. Flexible polyimides are more reliable, due to the fixed and reproducible spatial relationships between electrical circuits within the assembly, based on actual experience with weapon system reliability data.

TASK 2: CYLINDRICAL CIRCUIT BOARD

Process Optimization

General Dynamics performed the development and testing required to optimize the manufacture of the primary and secondary mirrors of the parabolic 94-GHz antenna, emphasizing rigidity, low thermal expansion, and thermal integrity. They also performed the development and testing required to optimize the manufacture of cylindrical multilayer printer wiring boards, and manufactured a sufficient number of boards to establish the reliability of the process to a 95 percent confidence level. A lot size of 20 pieces was sufficient to demonstrate an 85 percent reliability at a 95 percent confidence level, assuming no failures in the lot.

General Dynamics proposed an implementation plan which detailed the steps to be taken by the contractor to implement the results of the Basic and Option I efforts.

The manufacture and functional testing of five 94-GHz dish antennas included only those items required for test in the applicable referenced military specifications. No RF testing was attempted.

Support and Process Documentation

General Dynamics prepared a design package and support documentation that detailed step-by-step processing and process and solution control, to the extent that the developed process and results could be duplicated by others from the furnished package. They also assembled a pilot production line embodying the final developed processes and used it to qualify the process. To minimize expenses involved in establishing a pilot production line, off-line and/or unbalanced facilities were utilized.

A run of 16 94-GHz dish antennas and a run of 20 8-layer cylindrical boards with plated-through holes were completed for process and line verification.

Production Costs Drop 24 Percent

Compliant Air Bearing Gyros Built Better, Cheaper

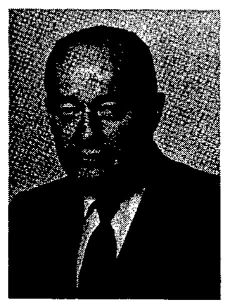
Under U.S. Army Missile Command sponsorship, Honeywell, Inc. (St. Petersburg) made significant advances in magnet fabrication, mirror fabrication, compliant layer molding, rotor balancing, and gyro testing—all to demonstrate improved manufacturing processes for the Compliant Air Bearing (CAB) Gyro. The process and tooling developments listed below have resulted in a 24 percent reduction in the projected production cost of the CAB.

- Injection molded magnet
- Magnet patterning process
- Diamond turned mirror fabrication
- Investment cast torquer housing
- Multicavity compliant layer molding
- Rotor balancing process
- Gyro test process.

Not only are the cost reductions significant, but the credibility of the estimates and the technical credibility of the CAB as a seeker gyro for cannon launched projectiles has also been established.

Reconfigured Design Necessary

Contract objectives were to develop improved manufacturing methods and technology for the production of a hydrostatic Compliant Air Bearing (CAB) gyro and to demonstrate the significant cost advantage this technology represents over conventional seeker gyro technology. The contracted work was based upon the CAB gyro assembly developed previously by Honeywell in conjunction with MICOM. Program effort was directed to implement the standard Copperhead folded optics system, and the CAB gyro was reconfigured to accommodate new optics and laser detection hardware. All subsequent manufacturing methods development was based upon this new gyro configuration.



WILLIAM G. ROBERTSON presently is assigned to the Parts Acquisition Program Office at MICOM. He received a BME from Marquette University and worked for Lear, Inc. for three years before going to work for the Army Ordnance Corps at Redstone Arsenal in 1952. In 1960, he returned to private industry for 14 years; in 1974, he returned to MICOM, assigned to Inertial Systems Development in the Guidance and Control Directorate. He has approximately 27 years of design experience in gyros and stabilized platforms.

The contract performance was divided into two phases—the Basic Program and the Option I Program. In the basic program, the methodology was developed for the manufacturing and assembly processes for each element of the CAB gyro. The Option I program demonstrated the fabrication, assembly, and test processes during the build of a pilot production sample of CAB gyros.

NOTE: This manufacturing technology project that was conducted by Honeywell, Inc.'s Avionics Division was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Bill Robertson, (205) 876-1020.

Performance Objectives

The CAB gyro seeker including the gas supply system is shown in Figure 1, while the major elements of the device are shown in block diagram form in Figure 2. The gyro includes a planar mirror on the front of the rotor, and this mirror is located in the exact same axial position in the projectile as the Copperhead mirror and in the same position relative to the pivot axis of the rotor. Therefore, the gyro is directly interchangeable with the Copperhead optics and detector assemblies. The unit is designed to exactly fit the Copperhead 155-mm projectile envelope and interface directly with the guidance electronics housing at the aft end of the gyro support housing.

The CAB gyro is designed for an angular momentum that provides drift performance within the Copperhead requirement. The spin axis to cross axis inertia ratio has been controlled by design, thus ensuring stable, nutation free operation. The gimbal angle freedom exceeds Copperhead requirements. Performance after launch shock of 10,000 g has been verified by test.

The salient features of the design are as follows:

- Two-Axis "Free Rotor" Air Bearing Gyro
- Compliant Bearing (EPDM)
- DC Torquing
- Optical Gimbal Angle Pickoffs
- Integral Gas Supply System
- Planar Mirror—same size as Copperhead
- Standard Copperhead Optics/Detector.

The advantage of this design over conventional seeker gyros can be summarized as follows:

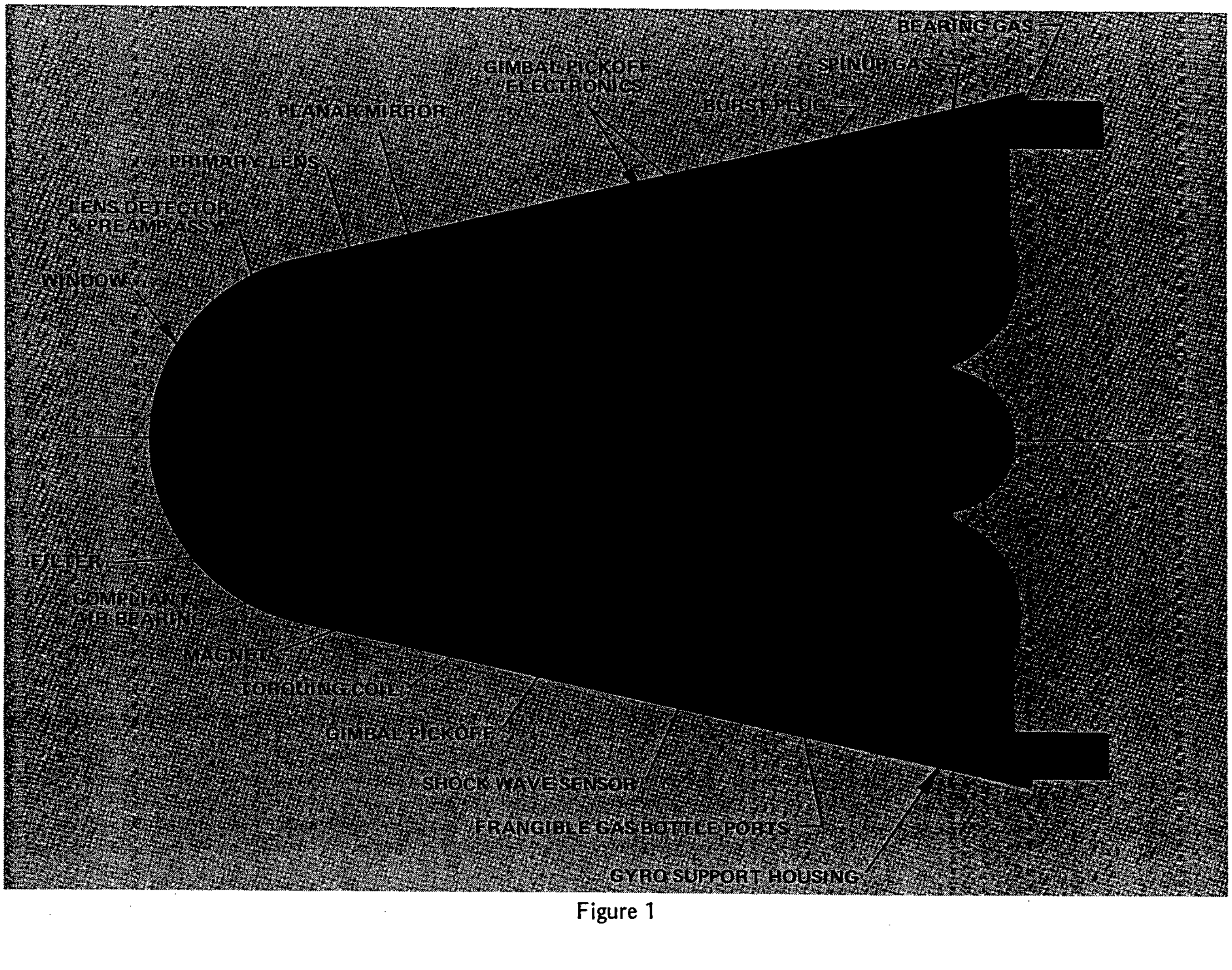


Figure 1

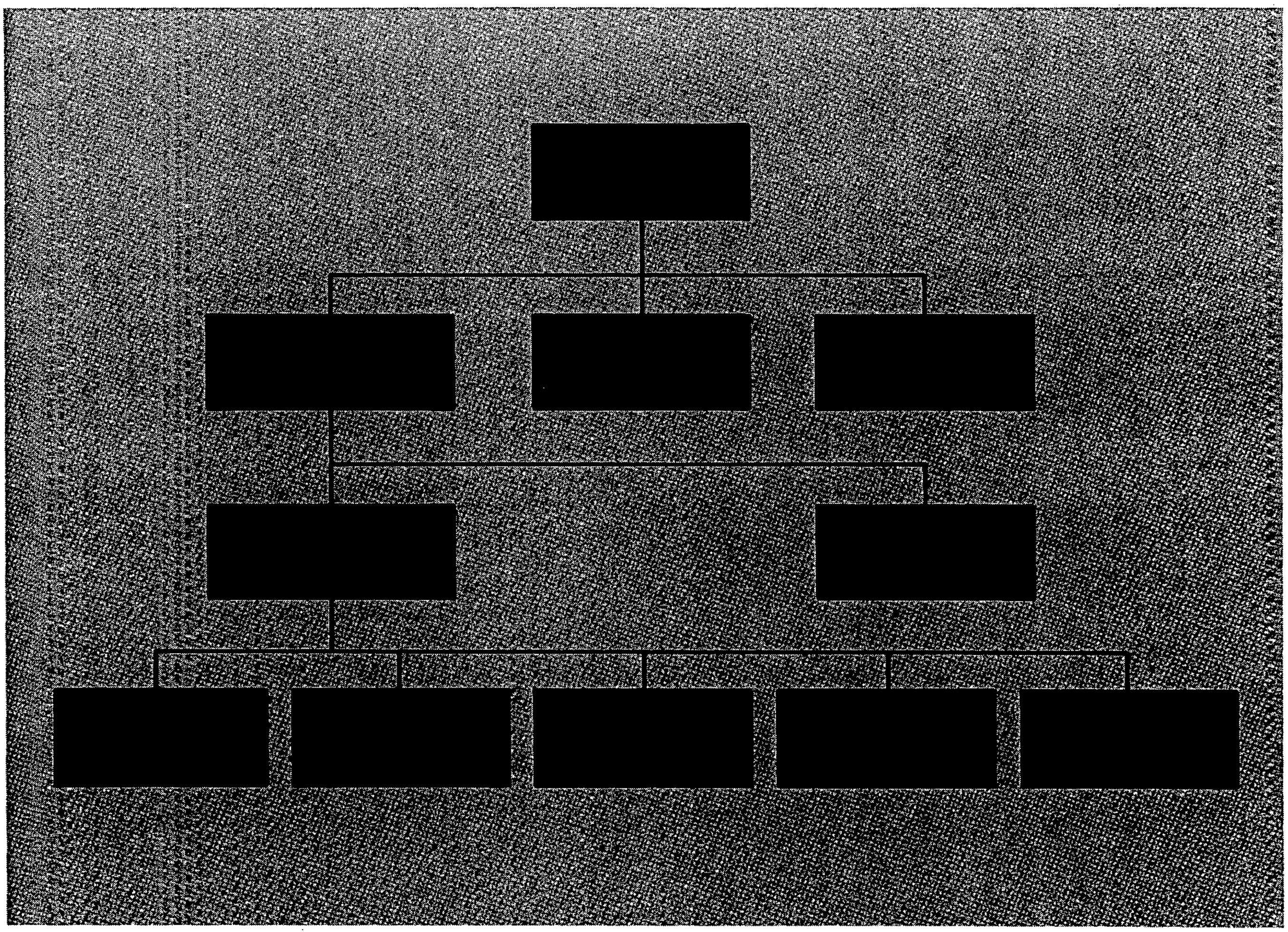


Figure 2

Cost

- Minimum Parts Count
- No "Gotcha"
- No strategic materials (no titanium or cobalt)
- Molded elastomeric bearing cavities

Performance

- Constant wheel speed (hero engine)
- No Coulomb friction (air bearing)
- Low Noise (optical pickoff)

Electronics

- Continuous DC Torquing (synchronization with speed not required)

Operation

A squib is initiated after launch, fracturing the seal on the bearing gas bottle allowing gas to flow through a gas flow regulator to the stator stem and exiting out 16 orifices around the spherical diameter of the stator, thus "levitating" the rotor. Immediately, the gyro torquer is activated, positioning the rotor for spinup, then the gas is released from the spin bottle by fracturing its seal. The spin gas flows through channels in the support and torquer housings exiting from tangential nozzles in the torquer housing. The exiting gas impinges on the turbine ring on the rotor assembly and accelerates the rotor to operating speed. The rotor speed is sustained throughout the mission by venting the center of the bearing with tangential "hero nozzles" in the rotor assembly. On the forward rotor half is mounted the planar mirror which reflects the incoming laser energy onto the forward mounted detector assembly.

Also mounted on the rotor is a magnet which provides the magnetic flux for torquing the rotor through a dc torquing system in both pitch and yaw. The spherical outside surface of the magnet is coated with a sawtooth reflective pattern from which the optical gimbal angle pickoffs read pitch and yaw angular displacements. Mounted on the torquer housing assembly surrounding the rotor and stator assembly are the pickoff assemblies which consist of an LED and a phototransistor. The output of the pickoffs is a pulse width modulated output with the percent modulation proportional to gimbal angle. Gimbal pickoff electronics are included in the gyro assembly to convert the output to a linear dc output proportional to angle with appropriate filtering. Also mounted to the torquer housing are the torquing coils for the dc torquing system. Mounted on the forward surface of the torquer housing is a lens housing which supports the standard Copperhead optics and detector assembly hardware.

The CAB Gyro Seeker uses the standard Copperhead window and interfaces mechanically with the Copperhead electronics housing. Only minor changes are required in the Copperhead electronics to integrate the CAB. A new torquer drive electronics board and modifications to the sequencer board associated with Gyro initiation timing sequences will make the CAB gyro seeker completely compatible with the Copperhead projectile.

MANUFACTURING PROCESSES

The objective of this phase of the program was to develop improved lower cost manufacturing processes for critical elements of the new folded optics gyro design.

Rotor and Stator Assembly

The rotor and stator assembly is the heart of the CAB gyro seeker and special emphasis was placed on critical elements of this assembly. Rotor and stator assembly is shown in cross section in Figure 3. The critical elements of this assembly which offered the greatest potential payback are the Torquer Magnet, the Planar Mirror and the stator assembly. Significant improvements were developed in each of these elements. The remaining parts, while important to the gyro function, are conventional machined parts made of low cost materials and therefore are not treated in any detail.

The torquer magnet on the original baseline direct optics CAB was a complex and expensive assembly. The magnet was made of (3) INDOX ceramic rings. Each ring was independently machined, ground to size and independently magnetized prior to bonding them together. An epoxy coating was bonded onto the spherical surface and then machined to provide a nonporous uniform surface for plating the optical pattern. The plating was a three step electroplating process using copper, nickel and a gold flash. After plating the whole magnet, the pattern was formed by selectively removing the plating using a mechanical mask and abrasive blasting. The ceramic material was selected to avoid the use of expensive and strategic materials such as the cobalt containing Alnico series; however, the use of ceramic dictated extensive grinding of each magnet segment. The use of three segments independently magnetized was required in order to achieve the desired flux distribution over the spherical diameter. The required uniformity could not be achieved with a one piece magnet with the available magnetizing equipment.

The key to success involved magnetic orientation of the particles in the mold so as to achieve maximum flux density per unit volume of molded material. The design of the tooling resulted in achieving all desired final dimensions as molded and provided a void free uniform spherical diameter on which an optical pattern can be directly applied.

The magnetizing of the one piece magnet is critical to achieving a uniform torquer scale factor independent of the gimbal angles. This scale factor is a function of the uniformity of the flux density after magnetization. Magnetizing was done using the unique two coil radial magnetizing fixture shown in Figure 4. The nesting of the magnet and the sizing and positioning of the coils were carefully designed to achieve the optimum uniformity. A prototype gyro built with the new one piece magnet and magnetized in this fixture was evaluated for scale factor versus angle.

After magnetization a reflective optical pickoff pattern is generated on the spherical O.D. of the magnet as shown in Figure 5. The high cost of the original concept was caused by the need

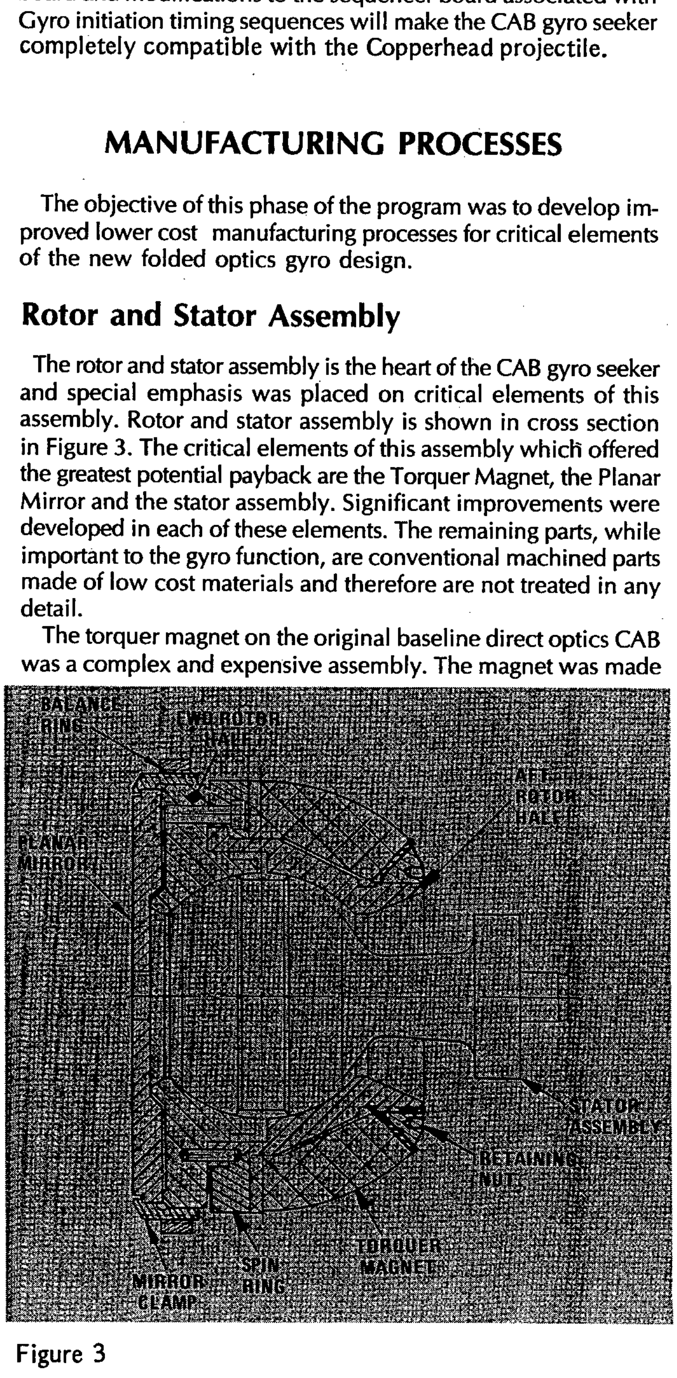


Figure 3

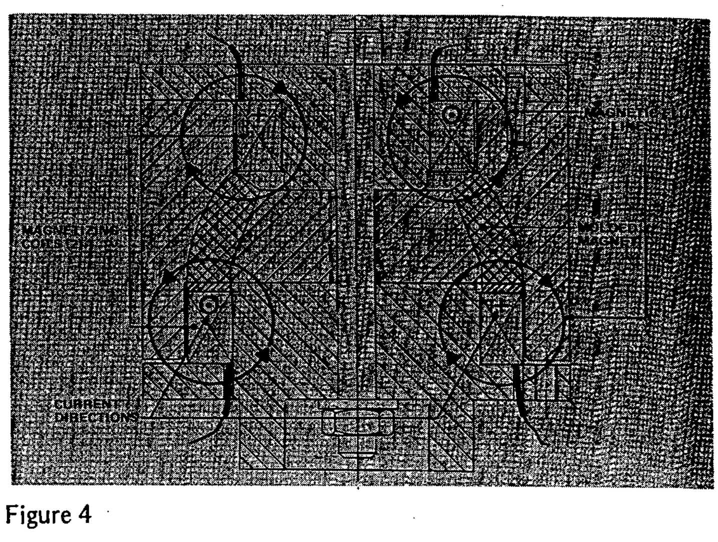


Figure 4

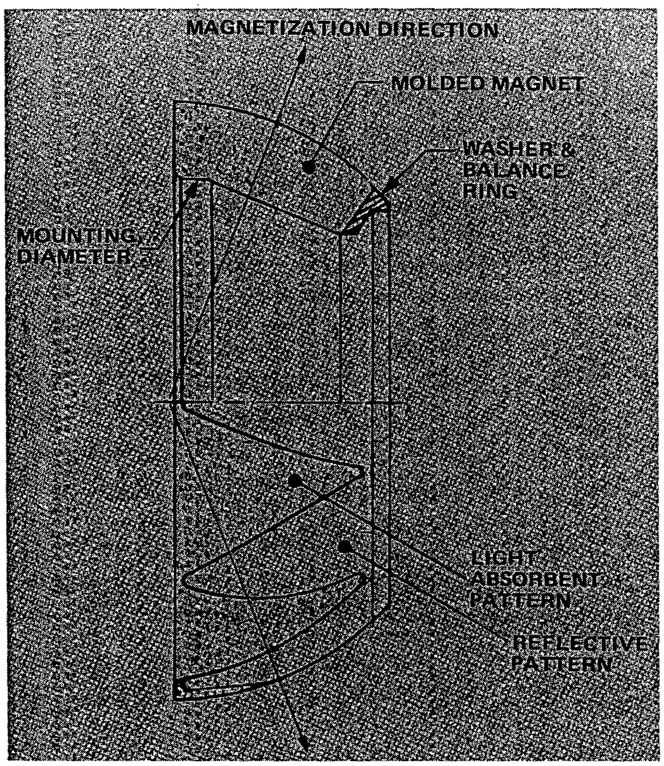


Figure 5

to seal the pores in the ceramic mateial with epoxy and the costs of the multiple plating operations. The molding process developed by Tengam produced the desired surface directly from the mold. Special testing of the pickoff assemblies was conducted to establish that the desired pickoff outputs could be achieved with other than a gold reflective surface. It was determined that adequate performance could be achieved with an optical quality white paint. This permitted the use of a low cost paint spray operation to replace the multiple electroplating operations. Standard adhesive tests were used to verify the integrity of the paint after cure. As in the original process, the pattern is formed by abrasive blast removal of absorbent areas using a simple mechanical mask. The geometrical accuracy of the pattern is controlled by the masking fixture.

The cost saving resulting from this new magnet manufacturing technology is substantial. The unit cost comparison is based upon estimated cost for the production of 130,000 magnet assemblies at 4,000/month. The total savings per unit represents a 97 percent reduction.

The CAB Gyro design objectives were to design a mirror equivalent in capability with that currently used on Copperhead, and to develop a mirror fabrication process which would be less expensive than the current Copperhead process. The Copperhead design utilizes an aluminum substrate which is integral with the gyro rotor frame. The cast surface is machined and nickel plated using an electrolytic plating process. The nickel is then ground and lapped to achieve the required surface finish and flatness. The planar mirror reflective surface is formed by vapor depositing a very thin layer of nichrome and very pure gold onto the lapped nickel surface. The Honeywell objective was to eliminate the labor intensive lapping operation and costly electrolytic plating process. This was accomplished by diamond single point turning of the aluminum substrate. In this concept the surface finish and flatness of the substrate is attained directly on the aluminum without the need for a heavy nickel plating and subsequent lapping.

The surface finish, flatness and mirror quality were successfully accomplished using the diamond turning process. This enabled Honeywell to complete the mirror process with a vacuum deposition of the highly reflective gold surface.

The vacuum deposition was accomplished at Honeywell's St. Petersburg manufacturing facility.

The reflectivity of the coated mirrors produced to demonstrate the process all met the reflectivity requirement. The mirrors were tested at the Bryson Laboratory in Safety Harbor, Florida. Tests were made at three different wavelengths.

The final mechanical configuration of the mirror provides the clear aperture required by Copperhead. The mirror is clamped to the forward rotor half with a threaded ring around its mirror surface through cannon launch. Five mirrors have been successfully cannon launched with two of the five tested afterwards at the MICOM simulation center. Honeywell's engineering estimate is that a 30 percent savings will be realized.

For the stator assembly, the folded optics configuration required locating the reflective surface of the mirror forward of the gimbal axes. Also, the rotor gimbal freedom had to be increased to meet Copperhead limits. These two requirements dictated a reduction in the bearing diameter. Other changes which resulted from converting from direct optics to folded optics were as follows:

- Shaft machining simplified
  Detector cavity deleted
  Leadwire holes deleted
- Orifice size increased
- Two orientation pins deleted.

The design of the stator assembly involves the machining of two pieces which are subsequently epoxied together to form all

the gas passageways. Both parts are machined from 7075 aluminum for the strength necessary to survive the cannon launch. Several successful cannon launches have verified the structural integrity of this assembly. Sixteen bearing orifices are drilled in the stator. The length to diameter ratio was minimized to control tool breakage. The spherical diameter of the ring is ground to a tolerance which controls the air gap when mated to the molded rotor halves. The projected unit cost savings represents a 28 percent reduction.

Torquer Housing Assembly

The torquer assembly originally consisted of a torquer housing, a spinup nozzle assembly, (4) torquing coils and erection coil. Several new design and manufacturing techniques were developed on this program resulting in significant cost reductions.

The improvements incorporated included:

- Converted housing from a machined part to a casting.
- Made spinup nozzle assembly integral with the torquer housing.
- Deleted the erection coil assembly by revising the spinup sequence.
- Developed production coil winding and forming tools.

A torquer housing casting was developed on this program. The investment casting tooling was designed and fabricated by Armstrong Mold Corp. in Syracuse, New York, and 30 castings were produced verifying the producibility concept. The housing provides the following functions.

- Base mounting diameter for interface with gyro.
- Built in positioning and support for torquer coils.
- Orthogonal planes for gimbal pickoff mounting.
- Mounting structure for Copperhead detector hardware.
- Integral spinup nozzles and passageways.

The casting is made from aluminum alloy A356-T6 per QQ-A-601. The castings receive radiographic and penetrant inspection per MIL-C-6021 Class 3 Grade C. The structural integrity of the cast housing was verified by successful cannon launches.

Machining of the casting is needed to

- Provide windows for mounting the two gimbal pickoffs.
- Size mounting diameters and faces for gyro base and optics assembly.
- Provide gas vent holes.
- Provide spin gas holes and nozzles.
- Provide tapped holes for attaching the base, lens support housing and optical pickoffs.

The torquer coil winding and installation process is basically unchanged from the original concept. Each of the (4) coils is identical and conforms to the envelope. Winding and forming fixtures were designed and developed to control the final sized form after impregnation and curing.

The torquer coil assemblies are cemented into the torquer housing, and the coils are self-aligned and positioned by the as-cast bosses in the center conical surface of the housing. The bosses also support the coils during cannon launch without the need for an expensive potting operation. The erection coil was also eliminated in the new concept by a simple change in the torquer rebalance sequencing electronics. Thus, just after bearing levitation the electronics provide for torquing the rotor first to a fixed position against the stop and then a controlled current is applied to each winding to torque the rotor to an on-axis condition just prior to spinup. The cost savings resulting from the new torquer housing assembly represents a 15 percent reduction.

The pickoff assemblies and the pickoff electronics are composed of two pickoff assemblies, one to sense pitch axis angular displacements and the other to sense yaw axis angular displacements. The pickoffs consist of an LED which illuminates the triangular reflective pattern on the outside diameter of the rotor magnet and a phototransistor which receives the reflected energy. The photodiode produces a voltage pulse for each of ten triangular patterns during one revolution of the rotor. The pickoff is positioned such that at gimbal null the pulse width represents a 50 percent duty cycle.

Gimbal deflections from null therefore either increase or decrease this modulation in direct proportion to the angle of displacement. The pickoff electronics convert this pulse width modulated output into a dc voltage directly proportional to angle for each axis. The pickoff electronics also produce a continuous ouptut indicating rotor speed. The rotor speed information is used for test purposes and could also be used to compensate torquer scale factor in the system electronics.

A task in this MM&T program was to develop the manufacturing methods for the pickoffs and pickoff electronics based upon the new folded optics gyro configuration.

The pickoff assemblies were not substantially changed as a result of the redesign to the folded optics gyro design, except that the positioning of the pickoff had to be revised as shown in Figure 6. The manufacture of the assembly consists of a molded plastic holder for mounting the optical components. The TIL23 Light Emiting Diode and the TIL601 phototransistor are both made by Texas Instruments. The mold for casting the pickoff holder was designed and built by Honeywell. The parts are mold-

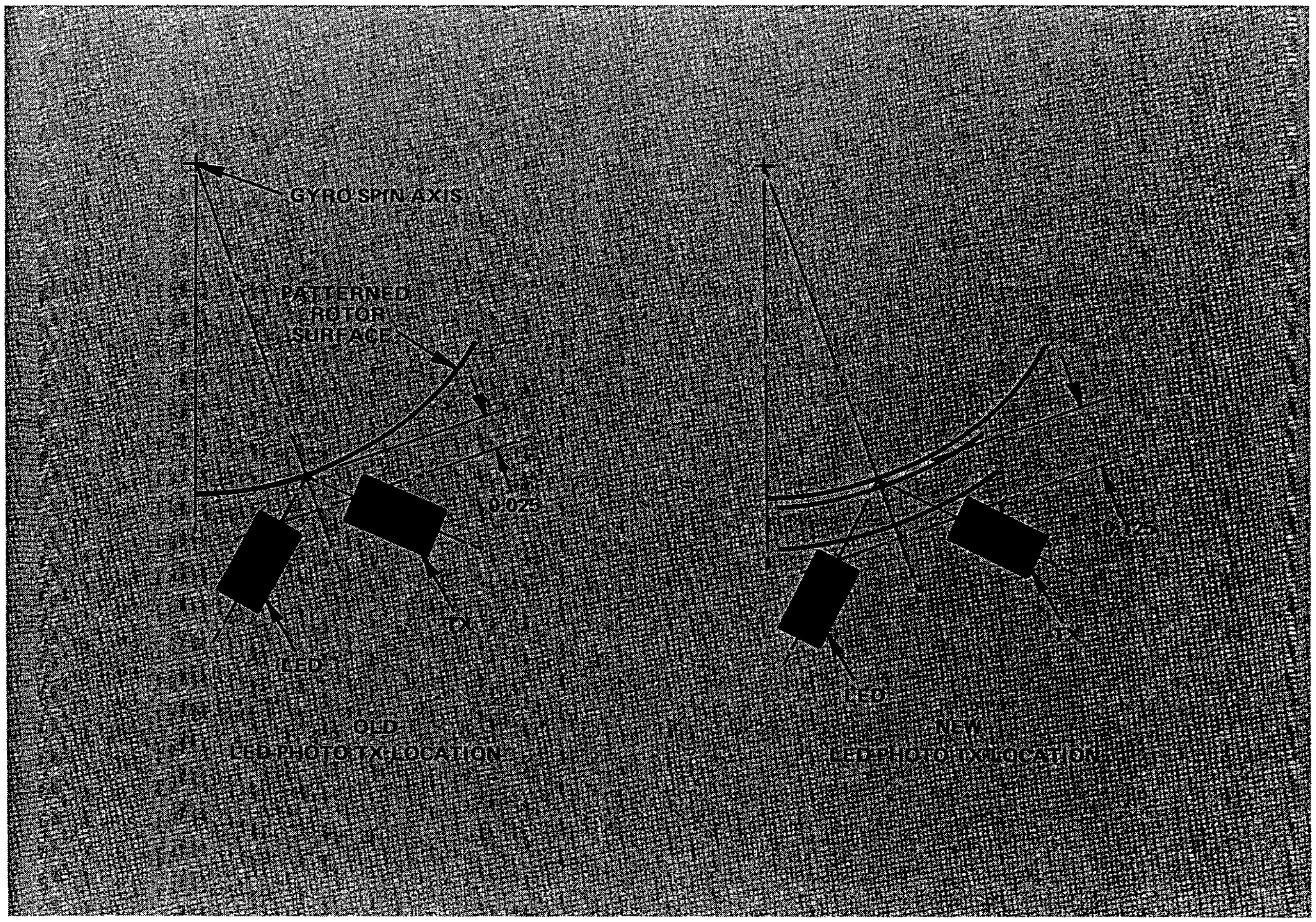


Figure 6

ed using a highly filled epoxy for dimensional stability and thermal conductivity. Minor secondary machining is required to drill the holes for the component mounting and to true the mounting surface.

The pickoff electronics accept the signals generated by the LED/phototransistor assembly. The rotating pattern on the rotor produces a pulse duration modulated (PDM) signal. The electronics are identical in both channels, except in one channel an output is added for purposes of monitoring wheel speed. The pickoff electronics develop a dc voltage level that is linearly proportional to rotor position. The electronics also contain biasing networks that allow the electrical null to be adjusted to coincide with the mechanical null.

The manufacturing process for the pickoff electronics was modified as a result of the conversion from direct to folded optics. The original concept utilized two printed circuit boards with discretes, mounted on the sides of the torquer housing. In the new folded optics design the area available for electronics was significantly reduced because the gyro had to be set farther aft to make room for the front end optics and detector. This necessitated the use of a vertical "donut" shaped sandwich assembly consisting of a lower board assembly and an upper board assembly. In addition the lower board had to be segmented so as to not interfere with the three shock wave sensors mounted on the gyro base. Because of the many interconnects required it was decided to utilize flex tape interconnect between boards and between the upper board and the pickoff assemblies.

Honeywell selected the Parlex Corporation in Methuen, Massachusetts to develop the printed wiring boards. Each printed wiring board consists of a single layer Kapton flexible cable sandwiched between two double sided rigid printed wiring boards. Approximately 15 of each assembly were produced by Parlex with excellent results. Component mounting and final assembly including select resistors and conformal coating was done by Honeywell using conventional procedures. The board assemblies are bolted to the gyro base with appropriate supports and stiffeners to assure survivability in the 10,000 G launch shock environments. Three units with these board assemblies successfully passed cannon launch.

The concept for final gyro wiring and interconnect with guidance electronics has been defined but no specific effort was included in this contract to develop these processes. All interconnects will consist of two hardware cable and connector harnesses and one flex tape with thermal compression bond connections. One connector will bring out all detector preamp outputs and the second connector will bring out the shock wave

and impact sensor connections. All gyro interconnects and preamp power will be brought out on the flexible wiring cable.

Gyro Support Housing

In the new folded optics version of the CAB, the gyro support housing becomes integral with the projectile seeker housing. The conical outside diameter is part of the exterior surface of the projectile. The features and functions of the support housing are as follows:

- Radial bolt attachment to projectile electronics housing at aft end
- Axial bolting of the rotor and stator assembly and the torquer housing assembly
- Threaded mounting for the pickoff electronics and the shock wave sensors
- Gas distribution from gas bottles mounted in rear cavity for bearing levitation and spinup
- Auxilliary gas ports for testing of fully assembled seeker.

The gyro support housings fabricated on this program were machined from 6061 aluminum bar stock. Cost studies were performed, however, to consider alternate lower cost manufacturing techniques. Considerations were given to near-net shape forgings, near-net shape impact extrusions and near-net shape castings. All would require some secondary machining. Analysis indicates the most cost effective approach is a near-net shape casting using 356 T6 or 357 cast aluminum alloys. The proposed casting configuration is shown in cross section in Figure 7. As indicated, only two inside surfaces and the external surfaces would require machining.

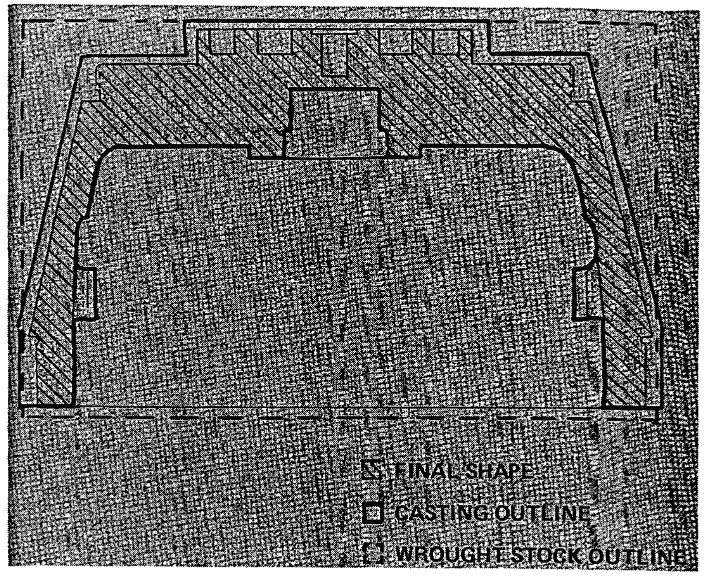


Figure 7

ASSEMBLY PROCESSES

The major thrust of the MM&T program in the area of the assembly of the CAB Gyro was centered in three critical areas:

- Compliant Bearing Molding
- Rotor Assembly Balancing
- Compliant Bearing Testing.

The Compliant Bearing Molding process is the single most important process in the CAB gyro concept. An elastomeric layer is bonded to the inside surfaces of the forward and aft rotor halves to form the hemispheric gas bearing cavities. This layer is molded in place using Ethylene Propylene Terpolymer (EPDM) rubber material. It is this compliant layer which enables the CAB gyro to survive the 10,000 g cannon launch without the need for a complex and expensive "gotcha" mechanism to absorb the shock. It is the compliant bearing molding process that generates the precision bearing cavity "as molded" without expensive grinding and lapping finishing processes normally associated with gas bearings.

The compliant bearing molding task consisted of the following elements: elastomer compound formulation and testing, mold design and fabrication, and molding process.

Extensive effort was expended to optimize the EPDM formulation for the compliant air bearing application. This effort was conducted at the Honeywell Defense Systems Divisions Materials Laboratory. The EPDM rubber compound was selected as the compliant layer elastomer because of its excellent compression set resistance, good flexibility at low temperature and low raw material cost.

The baseline EPDM formulation at the start of this program was reformulated. The development of the new formulation resulted in improvement in the following properties: moldability in multicavity mold, shrinkage, shelf life, and compression set.

The objectives of the multicavity mold phase of the MM&T project were as follows:

- Demonstrate that rotor halves can be molded independently
- Demonstrate that a multicavity mold is feasible
- Minimize amount of hand deflashing after molding

The mold design and fabrication was done by the Materials Laboratory at the Honeywell Defense Systems Division. Earlier programs had demonstrated the feasibility of molding a compliant bearing to the tolerances required using an engineering mold which produced one bearing at a time. Experimental gyros built with bearings from this mold have been tested and have demonstrated survivability after cannon launch.

The objectives of this program were to enhance the producibility and implement the changes required for the folded optics gyro design. The folded optics design required a reduction in bearing diameter. This scaling change was implemented without significant problems. The tooling concept selected was a 4 cavity mold, which molds two forward halves and two aft halves simultaneously. This size mold was compatible with our transfer press and it demonstrated the production concept. The same concept could be expanded to use larger size presses. The essential design of the mold is shown in cross section in Figure 8 showing one cavity of each type.

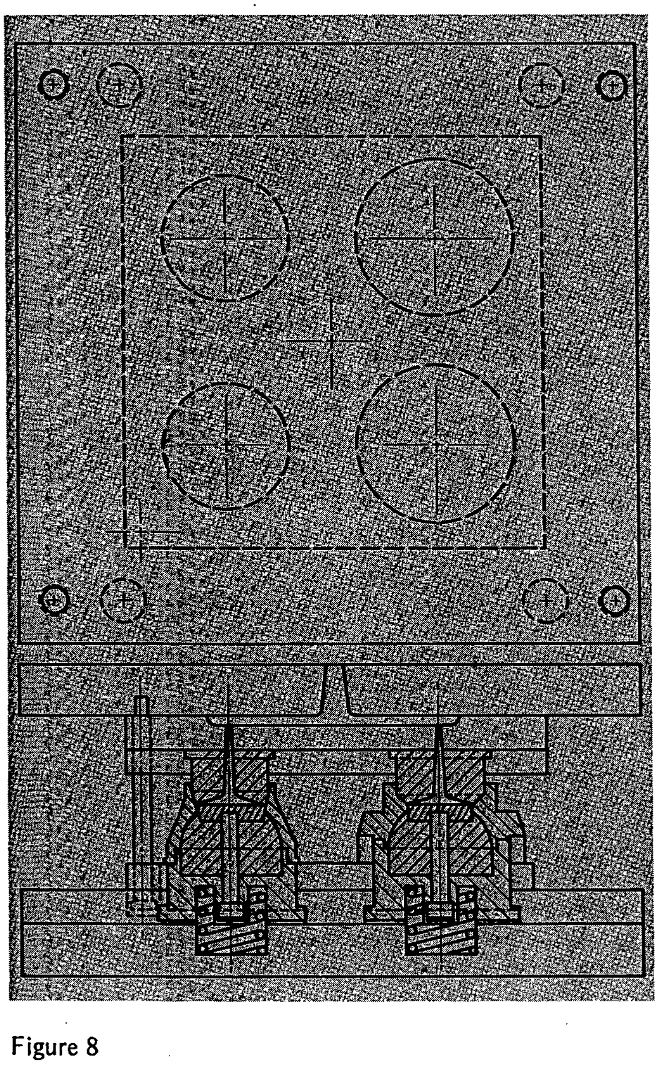


Figure 8

Several successful runs were achieved using this tooling. The need for some improvements was identified and should be incorporated in any follow-on effort. In early trials with the transfer molding spring pressure had to be increased to avoid leakage. These increased pressures resulted in distortions in the more flexible aft rotor halves. Ultimately, it was found that the spring force would have to be adjusted for each run because of variations in the geometry of one rotor half to the next. This is unacceptable on a production basis and a mold tooling change is needed. The best solution is to install expendable elastomer seals which would tolerate the variation in geometry and provide an effective seal at a lower spring force. Time and funding did not permit incorporation of this refinement on this program.

Significant improvements were made in the molding process as a result of efforts on this program. The most significant were: two step primer and adhesive system changed to one step primer, rotor halves molded independently, and shrinkage controlled by post vacuum baking of parts.

The original primer system used primer and adhesive applied to the grit blasted surfaces of the rotor in successive steps. The process was changed to a one part primer and adhesion testing was done to evaluate the peel strength of the two systems. The results indicate the suitability of the new process. The process time has been reduced with the one part system and the quality of the bond has been improved.

The mold design described in the previous section allows molding of rotor halves independently. This can be done by controlling mold tolerances such that the centerline of the spherical radii of each rotor half will coincide after assembly. Earlier engineering molds involved assembly of the two rotor halves around a spherical ball. This required more mold assembly and disassembly time. Loading of the new mold simply requires placing the halves on their mounting diameter. The aft rotors must be preheated prior to placing in mold. The mold design is such that the aluminum rotor halves fit line-to-line with the steel mold at molding temperatures.

Postcuring of the rotor halves is done after removal from the mold. The post cure is in a vacuum oven. The post cure removes the plasticizer, thus controlling shrinkage and stabilizing final sphere dimensions.

The balancing of the CAB rotor assembly cannot be done on conventional gyro balancing machines, because it is a "free rotor". Hence, the dynamic couple cannot be measured with force or velocity type sensors fixed to the balancer cradle. The wobble or dynamic couple must be measured optically using the mirror surface on the front of the rotor. Honeywell developed the concept for a CAB balancer with the American Hoffman Corporation in Lynchburg, Va.

The balancing concept corrects for wobble, or dynamic unbalance; it corrects for the static component (whirl) of the unbalance; and it corrects the static drift due to mass unbalance along the spin axis. The three corrections can be defined as follows (Figure 9):

(1) Adjust CG along spin axis to center of pressure.

(2) Adjust CG about spin axis to center of pressure.

(3) Adjust spin axis (principal axis of inertia) to be perpendicular to mirror.

A rotation of the CAB balance ring will change the balance along the spin axis. The balancing machine includes panel meters which tell the operator the amount of material to be removed from each balancing plane and at what angle about the spin axis. The two meters on the left show static balance corrections, and the two on the right show the dynamic balance corrections. The large meter in the center gives drift error in ten seconds when the button is pushed. The small meter in the upper center reads wheel speed in rpm.

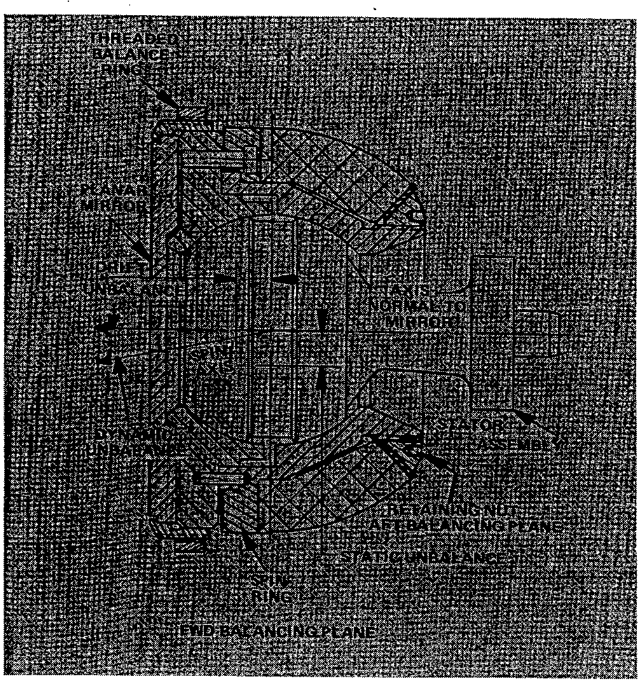


Figure 9

The sensing of the rotor mirror misalignment and drift comes from reflecting a laser beam off of the mirror on the front of the rotor. The reflected energy is received by a dual axis photodiode of high resolution. The outputs are fed to microprocessors which resolve the signals displayed on the panel meters. The static unbalance is sensed by a piezoelectric force transducer in the base to which the CAB assembly is mounted. Its output is also resolved by a microprocessor and displayed on the panel meters.

Experience has shown that rotors can be balanced in less than fifteen minutes. In production a fully trained operator is expected to average about 10 minutes per gyro. Other features of the equipment include controls for pressurizing the bearing and for rapid spin-up. The speed of the rotor is controlled by its own hero engine nozzles. There is a mechanical caging system for aligning the rotor spin axis prior to spin up. An electric drill is provided for precise removal of material to accomplish the balancing. Drill diameter and depth determine the mass removed. The rotor is stopped by hand when making a correction; however, bearing gas is left on to assure no contaminant can get into the bearing.

The quality of the molded cavity and the sizing of the stator ring are evaluated in terms of bearing performance after rotor and stator assembly. Four tests are made which assess the quality of the bearing as follows:

- Minimum liftoff pressure
- Operating pressure
- Radial bearing clearance
- Rotor terminal speed

All testing is done in one fixture and involves mounting the stator in the fixture and attaching the gas hose from the pneumatic test console.

The minimum lift-off pressure test is a good measure of the uniformity of the compliant layer and the cleanliness of the bearing surfaces. The test is accomplished by slowly opening the bearing gas valve on the pneumatic console and recording the minimum pressure at which rotor is observed to be floating free in all attitudes without observable restraint. The gas pressure is displayed on the gage in the pneumatic console.

After completing the minimum pressure test, the bearing gas valve is opened further until the bearing orifices and clearances are proper.

Bearing radial clearance is checked using a low contact force indicator, such as a Federal microprobe, by placing the indicator contact on the spin ring. The change in indicator reading is measured between gas on and gas off.

The final check involves letting the rotor run until the hero engine no longer accelerates the rotor. The terminal speed is measured using a conventional strobe light. Terminal speed is a measure of the bearing clearance and hero nozzle sizes.

In production, it is estimated that the entire test sequence can be accomplished in about 2 minutes.

Pilot Production

The Option I portion of this project involved the build and test of eight CAB gyro subassemblies. The build and test of these assemblies was accomplished with the following objectives in mind:

- Demonstrate the improved processes
- Document a baseline production build process
- Document a baseline inspection and test plan
- Establish document control system and traceability plans.

The pilot production program was conducted in Honeywell's Engineering Tactical Gyro Lab utilizing engineering technicians. Process engineers worked with the technicians in developing and documenting all processes. Inspection was done by the Honeywell Product Assurance organization in accordance with standard Honeywell procedures. The gyro testing was performed as an informal acceptance test conducted by test engineers who also developed the procedures and documented the data system. The semiautomatic engineering test equipment was designed and built by Honeywell.

Gyro Assembly Build

Eight gyro assemblies were built, and the simplicity of the design allowed assembly of these gyros without any special tooling. It is recognized, however, that future production build involving larger quantities will generate the need for some special holding and storage fixtures.

Final inspection of these gyros was completed on the follow-on contract which included integration with the optics and detectors. This postpones final conformal coating of the pickoff electronics, thus maintaining a degree of flexibility if further gyro testing should indicate the need for rework.

Gyro Testing

Gyro testing was done at the Gyro Subassembly stage in accordance with requirements of the specification. This is intended to be a production check of performance prior to integration of the optics and detector preamp assembly. This check includes the following tests and calibrations.

- Impedances
- Mirror alignment
- Pickoff scale factor/linearity
- Torquer scale factor/precession rate
- Static drift and elastic restraint
- Spinup, wheelspeed, and uncage error
- Static and G-sensitive drift.

Follow-on Work Suggested

Because of the success of this program, Honeywell strongly recommends that the CAB gyro seeker be funded as a Production Improvement Program (PIP) on the Copperhead program.

This program would include flight demonstration tests and qualification tests and prepare the CAB for a low rate initial production program. The front end of the PIP program should include some development funds to complete tasks not included in this program as follows:

- Complete development of gas bottle and regulator
- Complete development of interconnect between gyro and guidance electronics

Further effort is also warranted in the area of follow-up MM&T tasks aimed at further cost reduction and process development. These tasks would include:

- Development of near-net casting for gyro support housing
- Development of LSIC chip for gyro pickoff electronics
- Redesign of multi-cavity mold to improve yield
- Fully automate gyro testing.

Multifaceted Facility Built

Production of Infrared Detectors

RICHARD BRADY is a Project Leader in the Electronic Warfare Systems Division of the U.S. Army Electronic Warfare Laboratory, Ft. Monmouth, New Jersey, where he has worked on electro-optical projects for the past five years. Prior to this service, he spent eleven years in electro-optical work at the Combat Surveillance and Target Acquisition Laboratory at Ft. Monmouth. He joined the Government service in 1968 after receiving his M.S. in Physics from Fairleigh Dickinson University. He earlier received his B.S. in Physics from Brooklyn College.

Photograph Unavailable

Groundwork for higher rate production of infrared detectors of laser energy for laser warning receivers was laid upon completion of a recent AVSCOM mantech project. The Electro-Optical Division of the Perkin-Elmer Corp. undertook a program to develop manufacturing methods and techniques for producing interdigitated Indium Arsenide (InAs) detectors at a rate of 50 detectors per 40-hour week. Funded by the U.S. Army Aviation Systems Command and monitored by the U.S. Army Electronic Warfare Laboratory (ERADCOM), this work also involved a pilot production run and the design of a specific facility to build the detectors.

The detector array consists of two pairs of interdigitated comb-like photovoltaic elements formed by diffusion and mesa etching in an InAs wafer. Each comb element consists of nine parallel bars each 0.225 mm wide x 5 mm long. The bars of one comb are arranged alternately with the bars of the other comb to form an interdigitated structure. The detector chip is mounted on a standard integrated circuit header such as TEKFORM 8128.

During the course of the program, three sets of three engineering samples each and a set of eight confirmatory samples were delivered and the production rate was demonstrated through execution of a pilot run of 25 detectors.

Mesa Type Devices Chosen

At the onset of the program, two types of device structures were pursued: mesa and planar. The starting material in both cases is n-type single crystal InAs purchased in wafer form. For both types of devices, p-n junctions are formed by the diffusion of zinc into the InAs with the diffusion carried out in an evacuated, sealed quartz ampoule. For the mesa structure, the detector bar pattern is formed by etching mesas through the p-region and the p-n junction. For the planar structure, a deposited and suitably patterned silicon dioxide or silicon nitride film is used as a diffusion mask to form the detector bar pattern during the diffusion.

While ultimately the planar structure would be the preferable approach, being inherently passivated, comparison of performance data measured on both types of devices fabricated during the program showed that mesa-type devices generally outperformed the planar devices. Consequently, the decision was made to limit the remainder of the effort to the fabrication of mesa-type devices.

NOTE: This manufacturing technology project that was conducted by Perkin-Elmer Corp. thru the U.S. Army Electronic Warfare Laboratory was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVSCOM Point of Contact for more information is Bill Brand, (314) 263-3079.

The first set of engineering samples employed off-chip interconnects as shown in Figure 1. The specification calls for the output of the two combs to differ by not more than 10 percent when the device is scanned with a 1-mm-wide slit oriented perpendicular to the detector bars. With standard metallization, the resistance of the contact bars is high enough to cause the output signal of a detector to drop by as much as 30 percent when the illuminated area moves from the contacted end to the opposite end of the comb. In order to meet the matching criterion, one had to connect/interconnect all comb elements on the same side.

Introduction of a thick gold electroplating process which allowed 25 micron wide and 6 micron thick gold to be plated onto the evaporated contact bars reduced this signal loss to less than 4 percent. This led, in turn, to an improved mask design and the device shown in Figure 2.

The improved mask design resulted in better uniformity of detector response, higher average responsivity and, last but not least, it reduced the number of bondwires from 36 nonredundant ones to 4 pairs. The improved mask design was introduced with the second lot of engineering samples and used throughout the remainder of the program. A cross section of the device indicating the major process steps is shown in Figure 3.

Work Transferred to New Facility

Between the second and the third lot of engineering samples the activity was transferred from Perkin-Elmer's research facility to the newly constructed detector facility, ensuring that a significant portion of the program be conducted in a typical manufacturing environment. This transition implied that all the processes be executed on new and different equipment and in a production-oriented facility rather than in a research laboratory. Furthermore, the effort conducted through the second lot of engineering samples utilized cleaved wafers with the diffusion carried out in small 100 cubic centimeter ampoules, while in the new facility 38-mm diameter wafers were used and the diffusion was carried out in 1500 cubic centimeter ampoules. The switch to 38-mm wafers resulted in a less labor intensive fabrication (each wafer contains 8 detector chips) and allowed the introduction of batch processing methods.

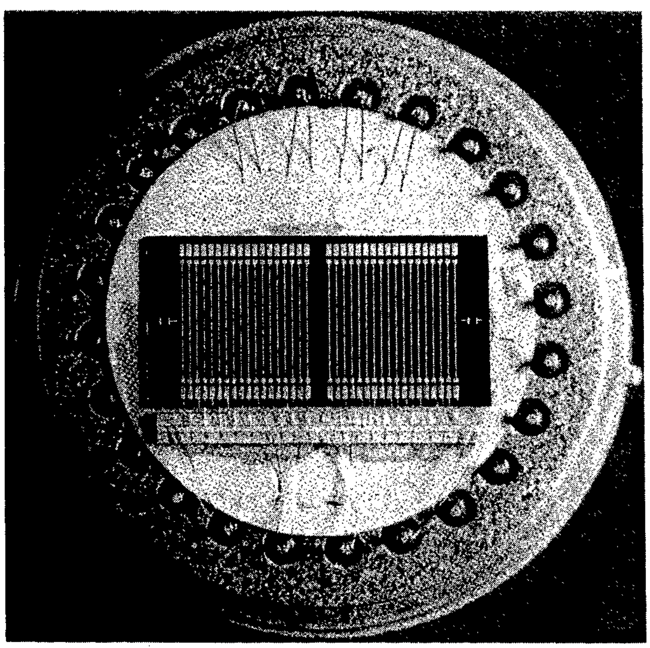


Figure 1

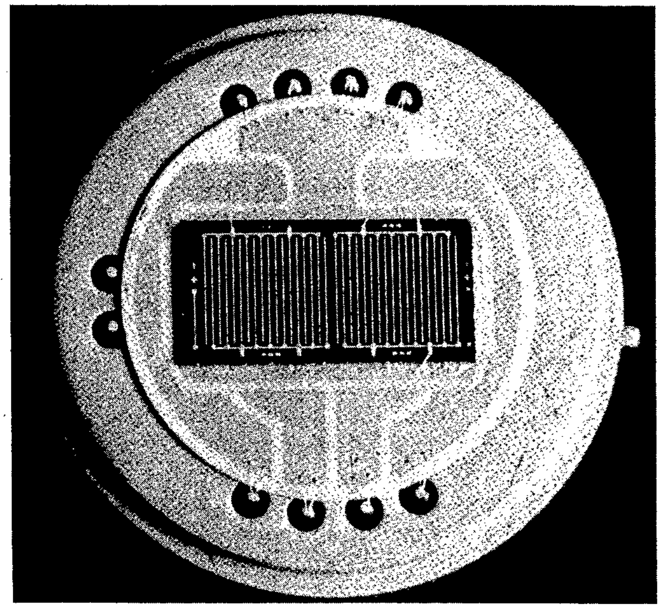


Figure 2

Test data acquired on detectors fabricated from starting materials of different carrier concentrations indicated that responsivity, crosstalk, and rise time vary significantly with carrier concentration. The zero-bias impedance of the devices is, obviously, also affected by the doping level of the substrate. Using the performance parameters measured on detectors fabricated through the second lot of engineering samples, one can relate detector performance to carrier concentration.

With the fabrication of the third lot of engineering samples, process run sheets were introduced to allow an easy and reliable monitoring of each diffusion run. Also, three lots of three engineering samples each and three separate test reports were delivered during this phase of the program. These reports present both raw and reduced data on zero-bias impedance, I(V) characteristic, responsivity at three wavelengths, specific detectivity D*, rise time, crosstalk, responsivity matching, uniformity of response, and isolation resistance.

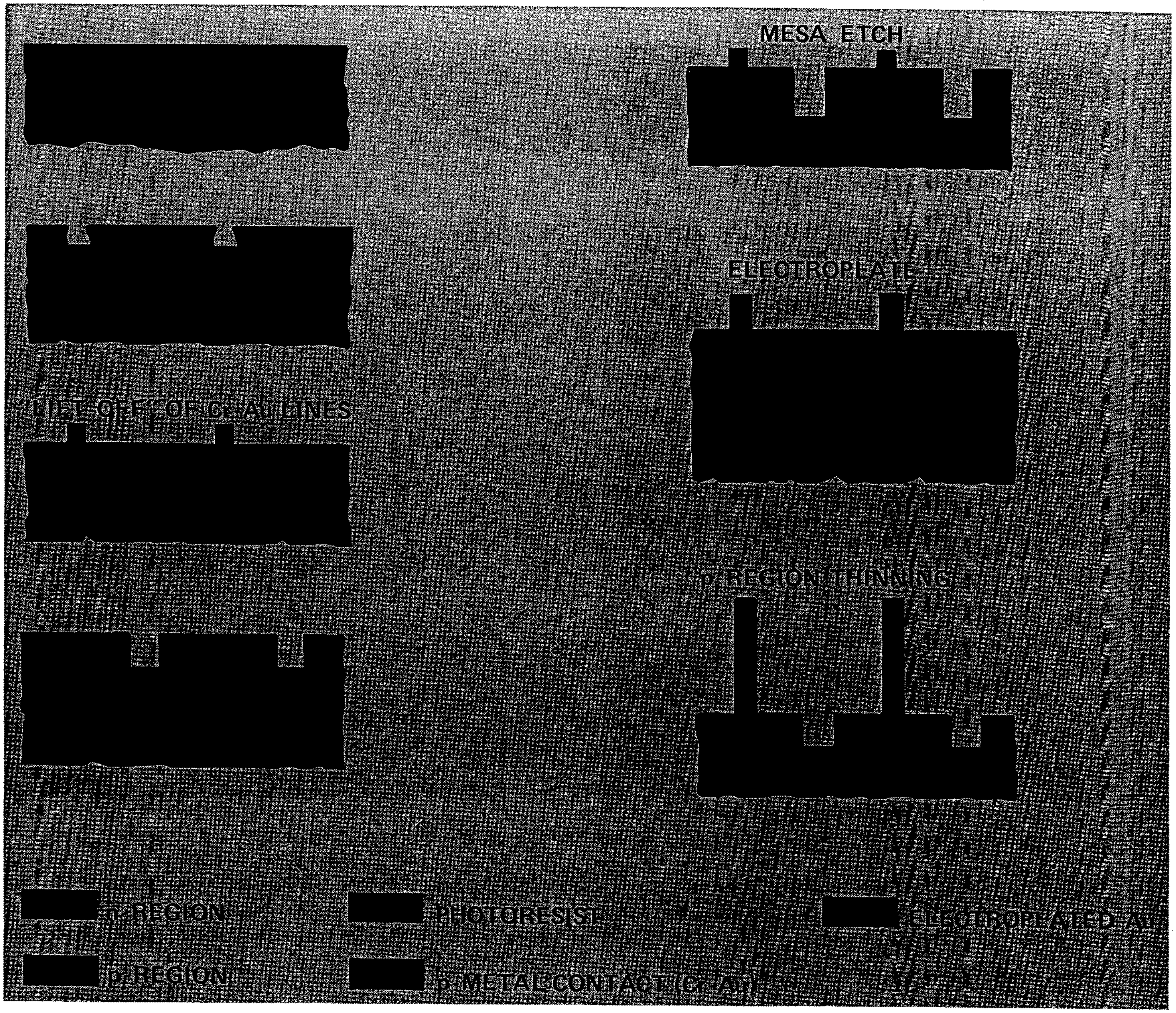


Figure 3

Confirmatory Samples Produced

Authorization to proceed with the fabrication of the confirmatory samples was received after acceptance of the second lot of engineering samples. The starting material used for the two diffusion runs providing wafers for these samples came from four different ingots. In addition, within the same ingot, wafers from both the seed and the tail end of the ingot were incorporated in an attempt to gather data on a range of starting material parameters which one might expect from MCP, the supplier of InAs wafers.

The eight confirmatory samples were selected from 24 packaged devices fabricated during this phase of the program. To assess the reproducibility of the process the mean standard deviation and maximum and minimum values of six of the measured parameters were determined for the eight confirmatory samples. The relatively narrow spread of the data indicated that the processes were under reasonable control and, therefore, appropriate for the pilot run.

Pilot Run Successful

A production rate of 50 detectors per 40-hour week was demonstrated through execution of a pilot run of 25 detectors. The fabrication process of the interdigitated InAs detectors can be broken down into 33 distinct process steps and the final electrical/optical test of the completed devices. The process flow is depicted in the flow chart for InAs detectors (Figure 4). To properly size the number of wafers required to yield at least 25 detectors, it was assumed that each wafer would yield only one acceptable device. Furthermore, to gain experience in batch processing, the number of wafers per diffusion run was increased from the eight used for the confirmatory samples to 15. Thus, the entire plot run was accomplished through two diffusion runs.

The large ampoule diffusion was introduced with the third lot of engineering samples. The process incorporates a bake-out of the loaded ampule while it is still on the ion pump. Diffusion Run No. 1 was in many respects an experimental one and also used to establish the appropriate bake-out temperature and time.

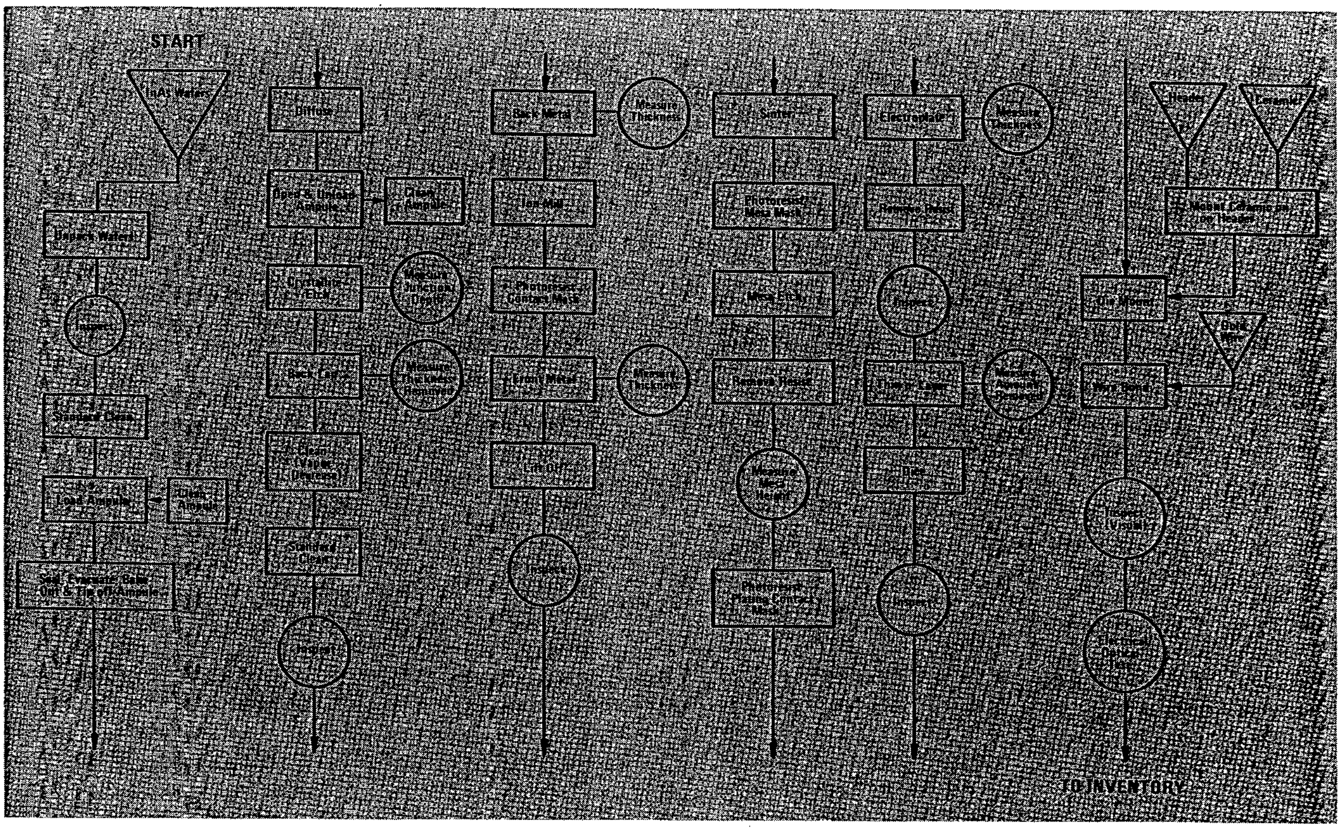


Figure 4

Thus, the diffusion depth attained in Run 1 does not fall in the pattern of all other diffusion runs. All diffusions were carried out at 480 C, the zinc arsenide charge was kept at 640 micrograms per cubic centimeter of ampoule volume, and the total insertion time in the furnace was monitored rather than the time at temperature. Inspection of the data indicated that there was a time difference of 50 minutes between insertion time and the actual diffusion time.

Inspection of the data shows that the diffusion velocity of 5 of the runs varies by about 22 percent. Of the total of 168 chips after dicing, 138 chips were die bonded and 30 were reserved in chip trays for future use; 130 chips were wire bonded and entered final electrical/optical test. Of the 130 devices tested, 86 met all acceptable criteria.

Of the 86 accepted devices, 25 were selected as pilot run samples. On all of the devices the following parameters were measured: zero-bias impedance, isolation resistance, rise time, responsivity, responsivity matching, cross-talk, uniformity of response (both difference and variation), and specific detectivity.

Final Evaluation Not Conclusive

During the initial test of the 130 packaged devices, 52 failed because of low zero-bias impedance and a soft I(V) curve. Subsequent experiments indicated that the junction deterioration did not occur during die or wire bonding. A soft I(V) characteristic and, thereby, a low zero-bias impedance can be caused by at least two mechanisms: dangling bonds and/or inversion layers. To test this argument one device was treated with AB etch, the etch used for both mesa etch and p-layer thinning, for less than one second; this treatment restored the I(V) characteristic and also improved most other parameters. The AB etch has an etch rate of about 1300 angstroms/sec and, thus, can reduce the p-layer thickness to the point where one loses most if not all responsivity.

After this initial experiment, the remaining 51 devices which had failed because of low zero-bias impedance received the AB etch treatment and were retested. Eighteen of the total of 52 devices met all specifications after AB etch. The 22 devices which did not pass had a thin p-layer to start with; the treatment created excellent diodes with very low responsivities. The outcome of these experiments restricted the introduction of a soft I(V) curve to the process steps between mesa etch and demounting after dicing.

While the present fabrication process is acceptable for production, it would be desirable to eliminate the post-assembly cleanup etch and the associated retest. Exact identification of

where the soft I(V) characteristic is introduced and how this effect could be avoided or counteracted was not possible during this effort and will have to be accomplished at a later time.

Using the labor and yield data of three runs, a production rate of 60 devices per 40-hour week was established. This production rate was limited by the dicing operation.

Detector Facility

The detector facility is a 7,500 sq. ft. one-story building which was designed to accommodate the fabrication of several types of detectors and optical filters. The variety of products to be handled in one facility resulted in a functional rather than an in-line layout (Figure 5). The facility consists of six functional areas:

Photolithography	(497 sq. ft.)
Chemical/Vacuum	(1092 sq. ft.)
Furnace	(619 sq. ft.)
Lapping/Dicing	(320 sq. ft.)
Assembly and Test	(841 sq. ft.)
Entry/Change/Storage	(256 sq. ft)
Total Working Area	(3625 sq. ft.)

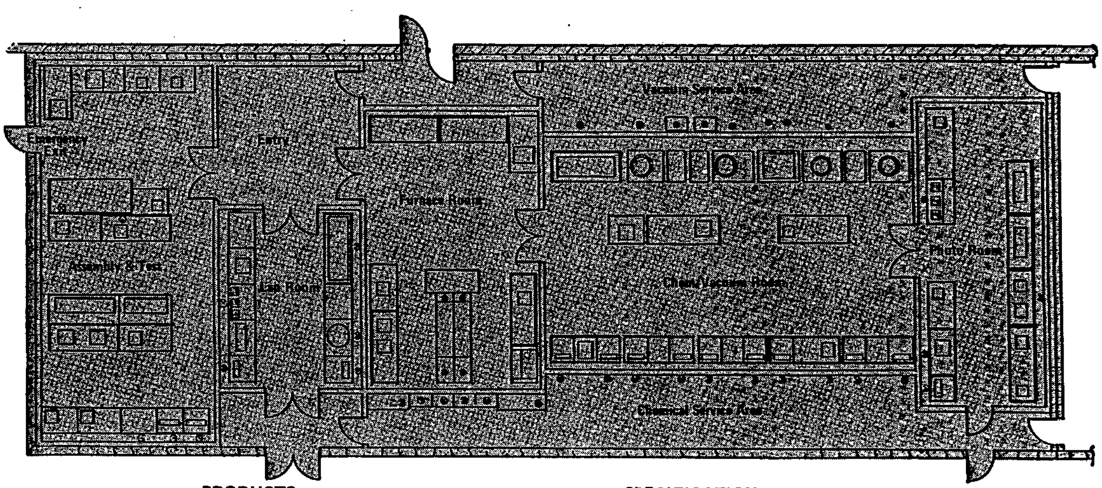
Chemical and vacuum service areas and HVAC occupy the remainder of the building. All working areas are maintained at 70 degrees plus or minus 2 degrees F and 35-40 percent relative humidity and are class 10,000 clean rooms but for the lapping/dicing area, which is class 100,000. All critical operations are carried out under class 100 vertical laminar flow hoods.

Several major pieces of equipment are utilized in this facility. In addition, there are ten custom designed chemical stations and a Perkin-Elmer built ampoule exhaust and seal-off station. Ancillary equipment such as microscopes, probe stations and curve tracers, dessicator cabinets, ovens, and a Tencor Alpha Step 200 Profilometer are placed at strategic locations.

Process Looks to Refinements

The processes developed during the engineering and confirmatory sample phase of this work were found to be repeatable and suitable for batch processing encountered during production. Further, the overall layout of the detector facility and its equipment and tooling met the anticipated production rate requirements, and the attained overall yield of 32.7 percent exceeded the original estimate by a factor of 6.5. A production rate of 60 detectors per 40-hour week was demonstrated; this rate would require a staff of six operators plus supervision.

However, while the process meets all requirements, it would be desirable to eliminate the post-assembly cleanup etch and the associated retest. This will require an additional effort to identify where the soft I(V) characteristic is introduced and subsequently introduction of the process changes required to eliminate the effect.



PRODUCTS

- Detectors — InAs, Si, $LiTaO_3$
- Etalons — Mica, Si

SPECIFICATION

- Area: 3,625 ft^2
- Class: 10,000
- Class 100 for Critical Operations
- Environment: 70 F ± 2, 40% RH + 0, -5

Figure 5

In-Process Testing the Key

Large Scale Hybrid Rework Reduced

Manufacturing problems related to the excessive physical size and complexity of large scale hybrid microelectronics have been substantially improved by a recently completed U.S. Army Missile Command manufacturing technology project. The work performed by General Dynamics' Pomona Division successfully established the manufacturing technology needed to design, fabricate, test and rework large scale hybrid microcircuits with cost effective yields. This technology features the use of bumped tape bonded to integrated circuit chips in order to permit electrical testing of the chips prior to assembly on the multilayer substrate.

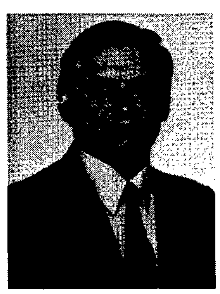
The fact that the bumped tape automatically bonded beams are substantially stronger (average 40 to 50 grams pull test) and always are prealigned again offers a potentially more reliable bond and less rework of wire bonds. In high volume production this will be significant.

It is recognized that the bumped tape aspects of total large scale hybrid processing are in their infancy and will be evolving in its maturity over an extended period of time. The other aspects of the process including items such as the engineering design, substrate processing, and fault isolation have made reasonable yields possible with relatively conventional techniques, with the bumped tape approach providing extra benefit.

Special LSH Problems

Large Scale Hybrid devices are defined as having a substrate area greater than 3.6 square inches, requiring a multilayer thick film metal interconnection, containing in excess of 30 active devices (primarily integrated circuits), and being in a hermetically sealed metal package.

Large hybrids have manufacturing problems not normally encountered in their smaller counterparts. Most of these problems are related to physical size, as larger areas permit the use of more integrated circuits; this results in greater circuit complexity and increased probability of component and interconnect failures,



PAUL WANKO is a Project Manager in the Manufacturing Technology Division, System Engineering Directorate of the Army Missile Laboratory, U.S. Army Missile Command. After graduation from Pennsylvania State University with an Associate degree in Engineering, he came to Redstone Arsenal while working for the Navigation Division of the Bendix Corporation as a field representative on the PERSHING Missile System. He began working for the Guidance and Control Directorate of the Army Missile Command in 1965 as a packaging designer and since has contributed to the designs of many Army missiles and launches. In 1970 he headed up the Hybrid Microelectronics Design Group in support of the new Hybrid Laboratory at the Missile Command. A few of his hybrid microelectronic designs are Range Safety devices, Detector Preamplifiers and Missile Auto Pilot. He is currently managing several MM&T projects and is responsible for the progress and reporting of these projects. He is a member of International Society for Microelectronics, Huntsville, AL chapter.

with correspondingly decreased hybrid level yields and increased fault isolation and rework. The emphasis of the work performed in this project was to introduce technologies for in-process functional testing and improved fault isolation.

Consideration was not given to system design or partitioning of large scale hybrids. Work was concerned wholly with manufacturing and testing of large scale hybrids and those aspects of design bearing upon their producibility.

NOTE: This manufacturing technology project that was conducted by General Dynamics' Pomona Division was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Paul Wanko, (205) 876-5619.

Topics Covered

A general industry survey was made of problems encountered in the manufacture of large scale hybrids. Solutions were proposed for those problems identified, processes were developed, and they were tested by building hardware.

Design considerations were limited to the substrate layout. Design standardization of the integrated circuit bonding areas on large scale hybrid substrates is required to implement recommendations for pretesting the integrated circuits.

Description of the fabrication processes for large scale hybrids was divided into three major processes for convenience: these were (1) substrate manufacture, (2) integrated circuit pretest including the application of all bumped tape automatic bonding operations, and (3) hybrid assembly and test.

Each of these fabrication processes has its own specific test requirements. They collectively contribute to successful testing of the completed hybrid; therefore, it was decided to include the investigation and solution of testing problems as separate parts of the fabrication processes' discussions rather than consider them independently. Similarly, rework was also addressed as part of the individual fabrication processes.

Processes Evolving Continually

The conclusions reached by MICOM and General Dynamics at the end of the project were as follows:

- In-process functional testing of integrated circuits can substantially improve first functional electrical test yield.
- Chip testing must exceed circuit level requirements in order to be effective.
- Because of total large scale hybrid complexity, rapid large area testing and fault isolation still are very significant to ultimate yield percentage.
- Secondary bumped tape automatically bonded benefits of lead bond reliability offer significant advantages.
- Large scale hybrid manufacturing process development for producibility upgrading is in a state of evolution which will continue to improve the process.

For improved producibility of large scale hybrids the bumped tape approach was demonstrated to be applicable and effective in pretesting the entire range of integrated circuit chips employed in this project. It was recognized that if customized test program software was created more exactly to reproduce the actual circuit operating conditions—as opposed to the more generic standard test programs—chip reliability at the hybrid functional test level could be further optimized. This was the recommended approach and the objective for production process evolution.

Two Phase Effort

The task was structured into two phases. The basic effort (Phase I) established design guidelines, materials, part standards, qualification procedures, fabrication processes, test and fault isolation techniques, and rework procedures. Phase II demonstrated through hardware build and test the producibility of the basic effort processes and procedures.

Phase I Objectives

- Verify Key Requirements for Large Scale Hybrid Manufacturing Process Development
- Conduct Industry Survey
- Establish Design, Fabrication and Test Guideline
- Formulate a Conduct of Program Plan

Analysis of the industry survey coupled with the background and experience that existed at General Dynamics verified that the trend in military hybrid microelectronics industry was toward substrate complexity and circuit line density, which exceeded present production standards by a factor of between 4 to 10 times.

In-process testability of integrated circuits to assure virtually 100 percent use of good components, particularly large scale and medium scale integrated chips, was considered a key element of cost effective large scale hybrid production.

Expeditious fault isolation and repair procedures for their overall hybrid circuits, upgraded centrifuge and leak testing at the package level, and ability to handle resistor and capacitor chip components were also identified as significant requirements.

A comprehensive manufacturing process development program was formulated to improve large scale producibility. It featured upgraded substrate design layout, application of bumped tape automated bonding (BTAB) for functional in-process IC testing and lead bonding, thick film substrate circuit technology, and hybrid level testing.

Phase II Objectives

- Demonstrate the Process Technologies
- Build Demonstrational Prototype Hardware
- Perform Functional and Reliability Testing
- Document Program Conduct and Process Results

Individual technologies identified in the large scale hybrid producibility guidelines were demonstrated with various test samples and engineering prototype design hardware. Ten mil lines, 12.5 mil diameter vias with 150 vias per dielectric layer for 4-6 layers can be produced with greater than 60 percent initial yields.

The application of bumped tape integrated circuit carriers coordinated with plastic slide test beds was demonstrated to be applicable for complex logic cell array and microprocessor integrated circuits as well as other integrated circuit chips.

In-process functional testing was demonstrated for these integrated circuits. Hybrid screening test showed hybrid g load tolerances of 5000 g in centrifuge testing. Twenty psi absolute was shown to be the maximum allowable pressure for helium leak testing.

Forty hybrid test samples were prepared for reliability testings. These samples were subjected to various time-temperature histories and evaluated for interconnection reliability.

Twelve complete large scale hybrids on 3.6 sq. in. substrates, 6 conductor layers, 31 integrated circuits (including operational amplifier, LCA, microprocessor, ROM, and RAM chips) and 98 total electronic components were fabricated. These hybrids, which were built to engineering design and fabrication standards, were tested for full electrical functional performance.

Oversize Hybrids Limited

One of the first tasks undertaken as part of the Large Scale Hybrid contract was a survey of military hybrid microcircuit manufacturers in order to obtain information regarding large hybrid design, substrate fabrication, assembly, test, and rework procedures.

While our survey did not disclose any consensus as to large scale hybrid construction details, we noted a reluctance to build microcircuits on ceramic substrates with areas of four square inches or more in a single cavity package. Difficulty in achieving hermetic seals, package flatness and strength, as well as difficulty in meeting MIL-STD-883 screen test requirements were the primary factors in the preference for smaller circuit assemblies.

Testing and fault isolation on a large microcircuit present problems due to the sheer multiplicity of electrical functions which are present. In addition, the mathematical probability of a large number of devices on a single hybrid all functioning properly is quite low unless the failure rate of the individual device is near zero percent. Inferences based on the survey indicate that the two most prevalent approaches to the problem of increasing large hybrid microcircuit electrical test yields are the use of ceramic chip carriers and tape bonding. Incoming chip probing is also used by some companies.

Manufacturing Considerations

One of the major driving forces in this manufacturing technique investigation was the improvement of the first functional test yield by providing tested integrated circuit chips for assembly into the hybrid circuit. Application of the bumped tape integrated circuit chip carrier and associated plastic slide chip handler and test substrate are the key elements which permit achievement of this objective.

Any large hybrid will have many discrete parts which are not integrated circuits and which do not lend themselves to the tape bonding approach. These are the resistors, capacitors, and diodes. Each of these has a finite probability of failure which will prevent a first functional test "pass" as surely as a defective integrated circuit. Therefore, specialized probe cards were designed to contact the fully populated multilayer thick film circuit in the open package. Planarity is of crucial importance for a large array of probes since in these circuits as many as 400 nodes may be probed simultaneously.

Loads Critical

The centrifuge and seal testing phases of the MIL-STD-883 hybrid microcircuit screen test procedures presented the most serious problems for large hybrid microcircuit production. Even a slight amount of bending or flexing during centrifuge testing or pressurization prior to fine leak testing could cause damaging peel stresses on the substrate package bond or "oil-can" the package lid, resulting in hermeticity failkure or shorting of the internal components. In some cases, a 500 g centrifuge test could destroy the entire hybrid. Without special strengthening of the package lid, resulting in hermeticity failure or shorting of the in area in normal kovar enclosures survive a 10,000 g test. This

occurs despite the fact that the tensile strength of the substrate-to-package adhesive has not been exceeded. For hybrid microcircuits greater than about one square inch in area the traditional leak test and centrifuge procedures used for hybrid circut manufacture are not useful process screens.

Design Criteria

When considering the development of large hybrids, the most important attribute is reduction in volume. Since volume is the limiting factor and less than 10 percent of the area occupied by discrete components is taken by the functional element itself, input/output and interconnection consumes the major fraction of the circuit area. Thus a single large hybrid generally is preferred over many smaller hybrids because of its greater interconnection density.

Interconnection Requirements

Since every available interconnection to a chip must be made, the footprint pattern (4mm, 5mm, etc.) selected will provide the required number of "feet" to make all available interconnections to the chip.

Using every available interconnection to a chip may result in some interconnections which are not electrically functional in a given circuit; however, since each chip type may be connected differently from circuit to circuit, all chip level pads must be contacted. As a result, the pad pattern on the substrate must allow for attachment of nonactive leads. These interconnections are retained for potential added circuit requirement and multiple use over many programs.

Figure 1 illustrates a chip with 46 interconnections used with a footprint with 52 leads ("feet").

Thick Film Planarity A Challenge

Large scale hybrid substrates are particularly prone to nonplanarity due to the large area. This makes the problem of laying down uniform screened layers more difficult; therefore, tight control must be exercised at incoming inspection of substrates.

The process of building up a thick film substrate with alternate layers of conducting and nonconducting materials has inherent in its concept the possibility of nonuniform thickness. As more layers are added to the substrate any variations in thickness are additively accumulated. This can lead to a resulting surface which is nonplanar. If planarity is not maintained under control, all subsequent operations are more difficult, if not impossible.

Multilayer Considerations

With large scale hybrids we have to deal with many more layers of conductor and dielectric. This is due to the increased number of components and the consequent need for interconnections within the hybrid. It is not uncommon for there to be

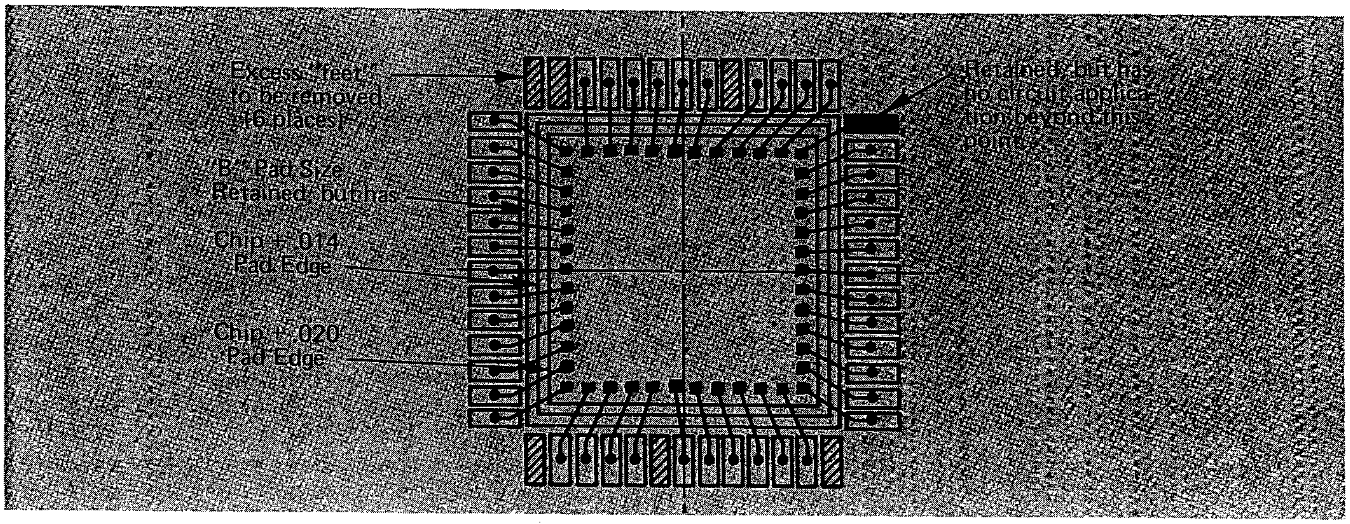


Figure 1

up to 10 to 12 layers (5 or 6 conductive layers); and, of course, there are many more interconnections between layers. All of this complexity leads to the opportunity for manufacturing and design errors to creep in. It is imperative that these substrates be thoroughly tested prior to assembly. Errors must be caught as early as possible in the manufacturing process while value added is the lowest.

The required measurement is simply circuit path conductivity (shorts and opens). Also, substrates may have thick film resistors which must be checked and trimmed to the right value as well.

It is hard to appreciate the number of nodes which may have to be checked in a large substrate. Some large substrates have upwards of 400 nodes. It is necessary to use a programmed substrate tester to perform this operation, as the number of individual tests required precludes manual testing.

It is impossible to check all possible situations so typically only a few thousand are considered. A second characteristic of these nodal arrangements is the frequent necessity to probe very closely spaced positions. Probe cards with as many as 400 probes spaced closely together are not available; therefore, the option chosen is to use smaller probe cards with fewer probes and test sections, perhaps quadrants, independently. This practice has the effect of testing four areas but not testing interconnections between the areas.

Rework Subjective

As a policy, thick film substrates should not be reworked after firing. Due to the cost factor in building large area, multilayer thick film patterns on large substrates the rework must be shown to be cost effective as opposed to scrapping the substrate and initiating a new fabrication start.

Figure 2 represents th process flow which General Dynamics Pomona is presently utilizing during large scale hybrid fabrication.

Pretest Process Development

The flow chart shown in Figure 3 represents the various operations associated with the mating of bumped tape to integrated circuit chips and the subsequent testing and disposition of these leaded chips. A proposed bumped tape work center in which these flow chart functions could be performed in an efficient, coordinated manner is shown in Figure 3, also.

In referring to the flow diagram we see that the initiation of activity in the work center requires an input of materials which,

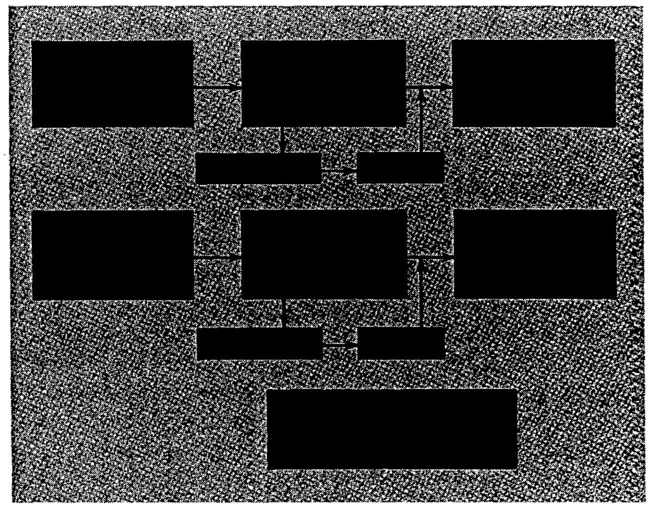


Figure 2

in the far left block of the flow diagram, is labelled 'BTAB MACROKIT SUPPLY." Typically, this kit would contain a large number of IC chips of a given chip type along with sufficient, compatible tape.

Thus far a measuring microscope has been used as the inspection tool (Figure 4); tape quality is examined in accordance with criteria established during earlier work on a Navy bumped tape contract.

The carriers (Figure 5a and 5b) (Lexan-Polycarbonate per Federal Specification L-P-393a) act as the storage and test vehicles for the lead formed chips.

Process Tests and Evaluation

The reliability of the bumped tape chips is directly related to the quality, uniformity, and integrity of the ILBs and the formed leads; therefore, the performance of the ILB machine and the excise and form machine are crucial in chip-to-tape assembly. Figure 6 shows a chip test fixture.

Process Specifications

The specifications for large scale hybrids are in essence the same as those used for standard smaller hybrid microassemblies. Two notable exceptions for circuits using bumped tape assembly techniques involve outer lead bonding of the leads of the bonded device to the substrate footprint and rework and repair of bumped tape mounted chips. Process flow is presented in the accompanying flow chart (Figure 7).

Producibility Hardware Varies

There are two types of demonstration hardware: fully functional units and reliability demonstration hardware in which the

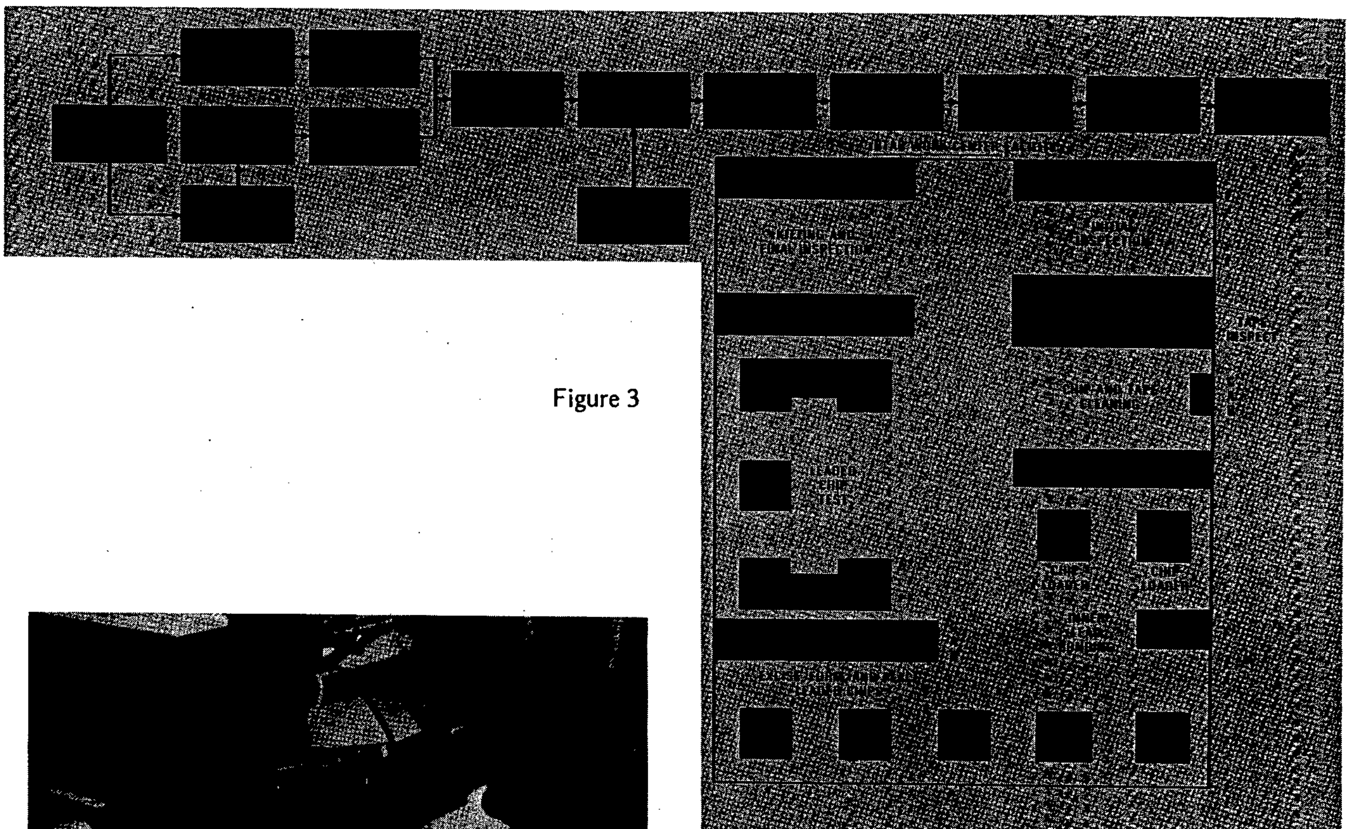


Figure 3

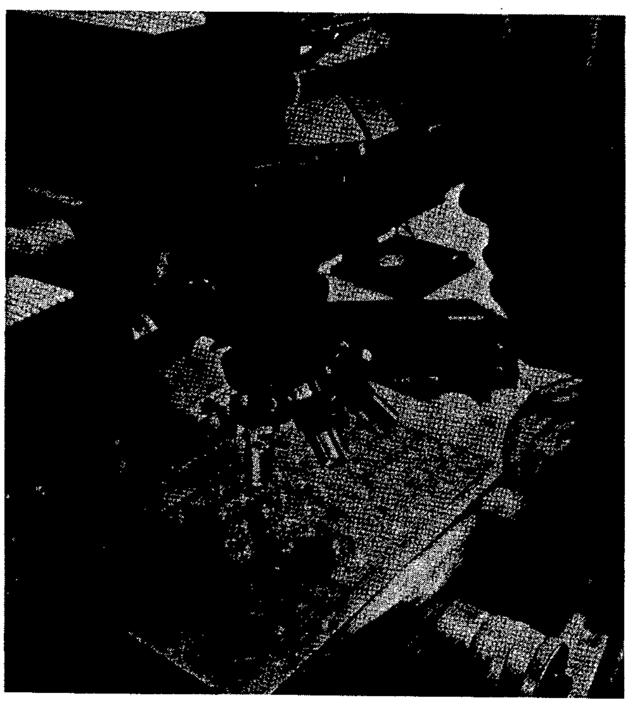
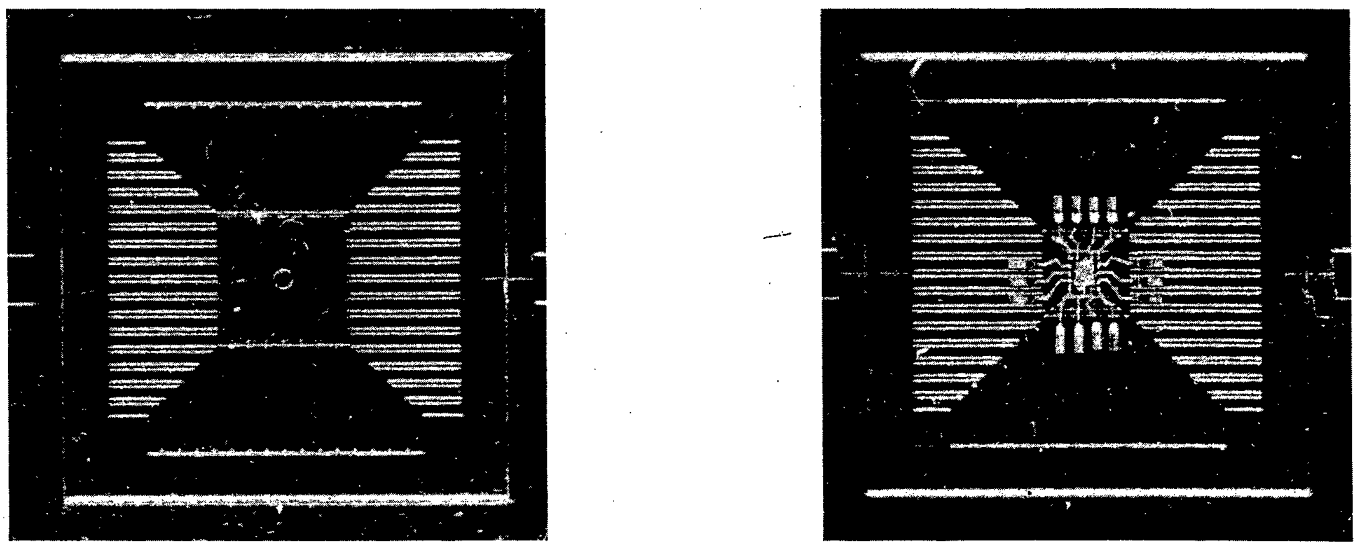


Figure 4

viability of the large scale hybrid processing is assessed. The reliability hybrids were constructed on the same multilayer substrate and enclosed in the same package type as the functional circuits. These substrates are populated with thirteen integrated circuits having tape lead connections between the device bonding pads and the substrate, while four IC's are bonded with 1 mil gold wire bonds. Also, there are 12 resistor chips, wire bonded, and six capacitors. The reliability hybrid is shown in Figure 8. The wires visible on the left side of the substrate serve to connect the operational amplifiers directly to the package pins in order to permit testing of these devices without removing the package lid. Each circuit is composed of 292 tape bonded leads and approximately 300 wires.

The second type of demonstration hardware consisted of twelve circuits which are identical to the final engineering



(a) (b)

Figure 5

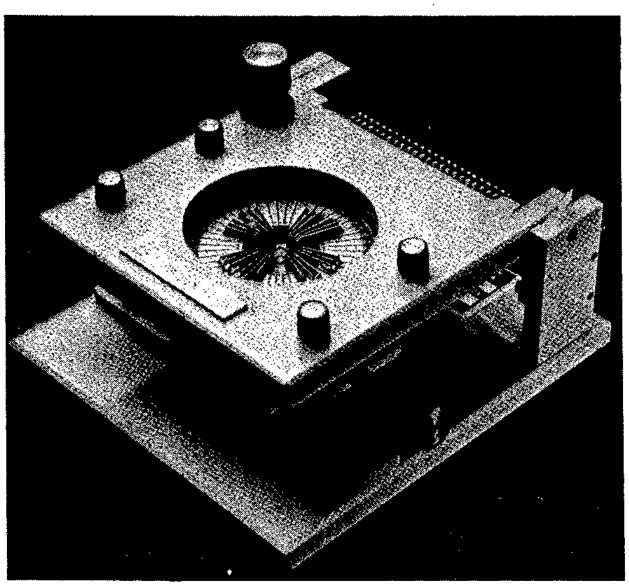


Figure 6

development version of the position computer circuit to be used in the Stinger Post weapon system.

The main function of this circuit is to convert digitally encoded target data into position information. Data calculations performed by the microprocessor discriminates a real target from false targets. The circuit generates a precession signal that keeps the gyro optics pointed in the direction of the target. This circuit is constructed on a ceramic substrate 3.6 square inches in area which has six conductor layers, five double-printed dielectric layers, and five via fill layers. There are 670 interconnection vias between conductor lines. The resulting multilayer substrate is populated with 98 electronic parts, including thirty-one integrated circuits. These integrated circuits range in complexity from simple inverters to a microprocessor, and include operational amplifiers, logic cell arrays, and ROM and RAM chips. In addition to the active components, the circuit contains 40 chip resistors, 14 capacitors, and 12 diodes. The complete hybrid circuit is shown in Figure 9.

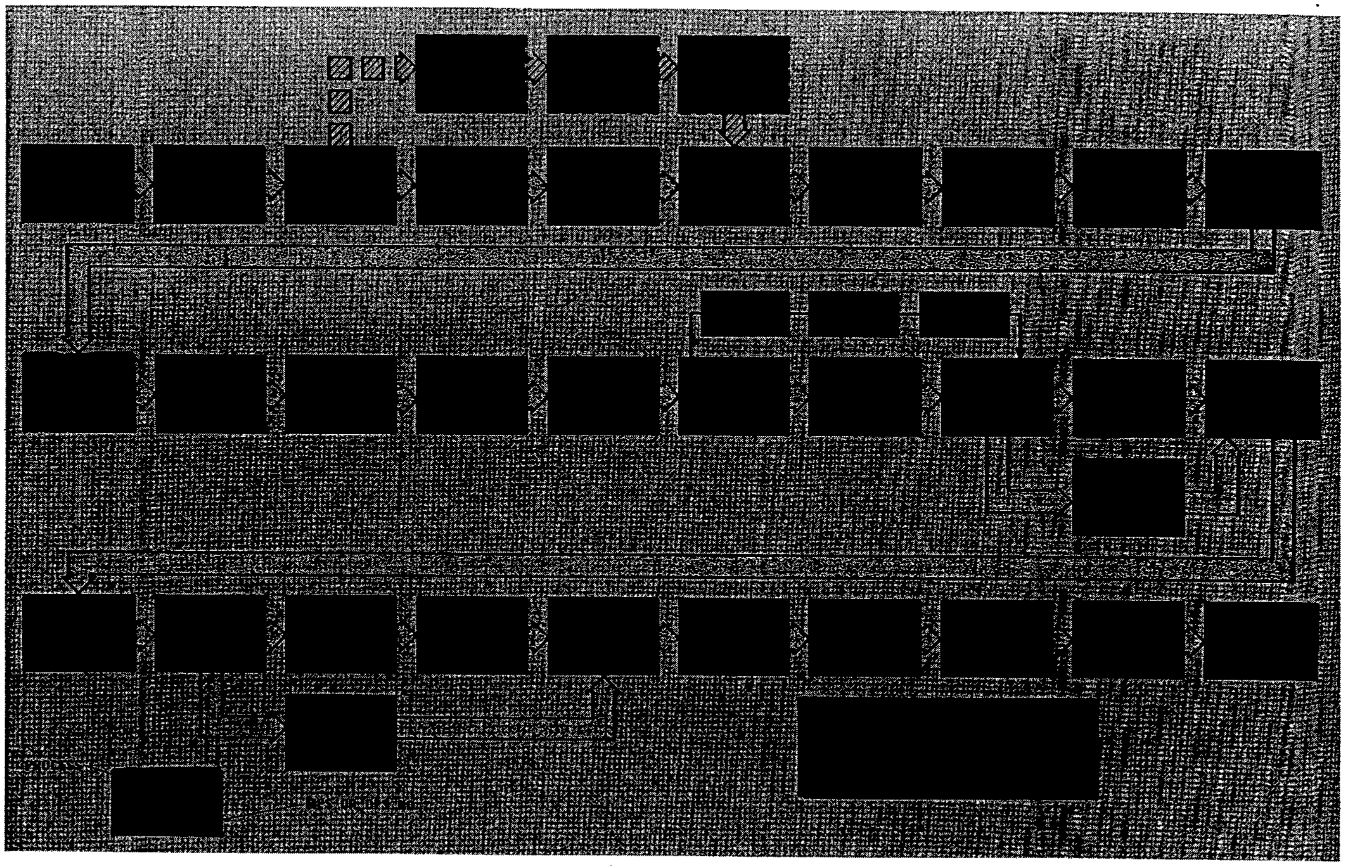


Figure 7

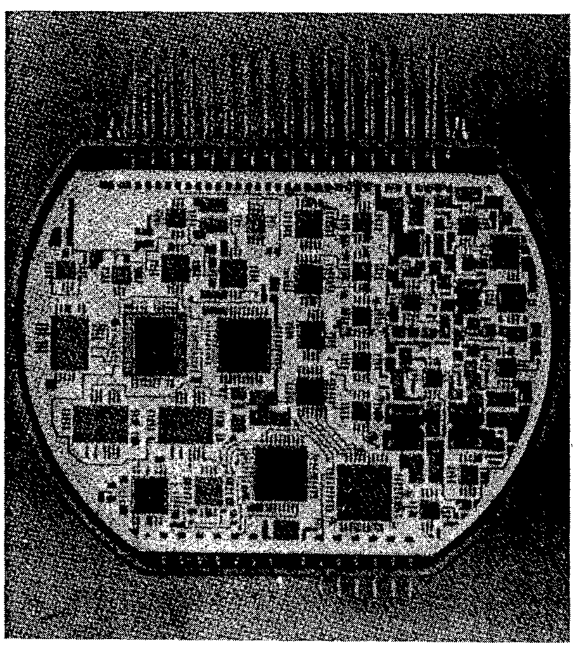


Figure 8

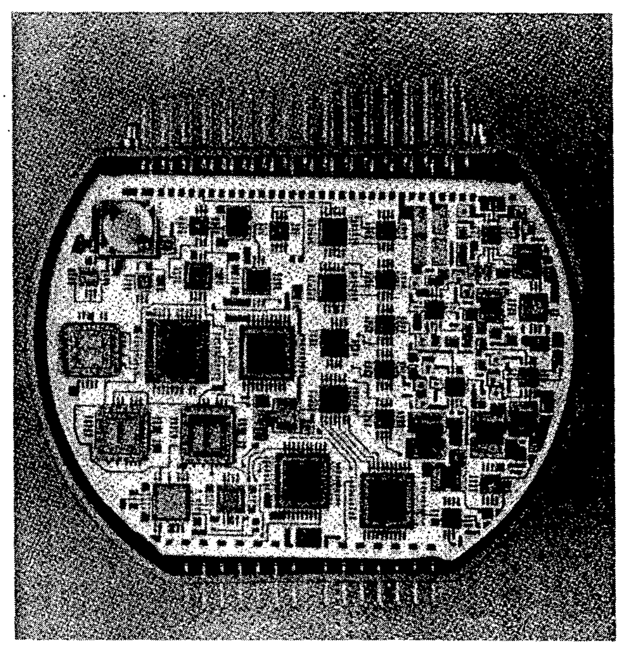


Figure 9

Multiple Benefits Realized

Ultrasonics Assists Tough Material Machining

BRUCE S. PARK is an Industrial Engineer in the Production Technology Branch, Directorate of Procurement and Production, U.S. Army Aviation Systems Command (AVSCOM). He holds a B.S. of Science in Civil Engineering from the University of North Carolina-Charlotte, and he graduated from the DARCOM Intern Training Center. During his six years at AVSCOM, he has performed a wide variety of engineering duties, including service on "should cost" teams, as Conference Coordinator of the AVSCOM Manufacturing Technology Conference III, as a member of the Nondestructive Testing Subcommittee of the Manufacturing Technology Advisory Group (MTAG), and activity as Project Engineer in the AVSCOM manufacturing technology program.

Photograph Unavailable

Editor's Note: Work on this project was performed at Sonobond under the guidance of Janet Devine, Vice President of R&D, and Philip C. Krause, Vice President of Marketing. Attention is called to the excellent references and documentation in their report, which is available from the U. S. Army Aviation Systems Command technical representative (see Note opposite). Unusual abstracts from foreign sources are presented in the Final Report, Project 7156.

Ultrasonics has established itself in still another manufacturing operation following completion of a machinability MM&T project by Sonobond Corporation for the U.S. Army Aviation Systems Command. By providing ultrasonic activation of cutting tools during the machining of unusually difficult-to-machine materials, AVSCOM has increased material removal rates of these tough to shape materials by as much as 700 percent.

A tool post for ultrasonic activation of cutting tools on a turret lathe was designed, fabricated, and given preliminary evaluation on a LeBlond engine lathe, turning difficult-to-machine wrought metal alloys including ESR 4340 steel, 4340 steel, 9310 steel, 17-4 PH steel, several titanium alloys, and Refractaloy 26.

With the ultrasonic assist, metal removal rates were increased by factors up to 730 percent, tool wear and tool breakage were reduced, and tool chatter was eliminated. Ultrasonically cut chips had a larger curl radius indicating lessened strain, lower hardness, and less heat discoloration than conventionally cut chips. It was recommended that the ultrasonic tool post be refined and installed on a turret lathe for evaluation in a production environment.

Project Conclusions Reached

(1) Ultrasonic activation of cutting tools greatly facilitated the lathe turning of wrought metal alloys that are ordinarily difficult to machine, including ESR 4340 steel, 9310 steel, 4340 steel, 17-4 PH steel, several titanium alloys and Refractaloy 26.

(2) Rates of material removal for these alloys were increased by factors ranging from about 175 percent to more than 700 percent with ultrasonic assist.

(3) Both cutting speed and depth of cut were substantially increased over recommended standard cutting parameters.

(4) Tool wear, which is particularly severe in conventional cutting of such materials as ESR 4340 steel and Refractaloy 26, was significantly reduced with ultrasonic activation.

NOTE: This manufacturing technology project that was conducted by Sonobond Corporation was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVSCOM Point of Contact for more information is Bruce Park, (314) 263-3079.

(5) Tool breakage occurred less frequently with the ultrasonic assist, indicating reduced tool loading.

(6) Ultrasonically cut chips showed a larger curl radius and a lower hardness, indicating lower chip strain as a consequence of lower tool/chip friction.

(7) Chips from ultrasonic cutting showed less discoloration than conventionally cut chips, suggesting reduced heating effects.

(8) Tool chatter, which frequently occurred with heavy non-ultrasonic cuts, were instantaneously eliminated when the ultrasonic system was activated.

(9) No consistent effect of ultrasonic activation on surface roughness was apparent under the conditions investigated.

(10) The turret-type ultrasonic tool post is practicable, with interface modifications, for installation on a turret lathe.

Ultrasonic Power Increased

The program was undertaken to evaluate the technological and economic benefits achievable with ultrasonic energy application during lathe cutting of difficult-to-machine materials and to define requirements for ultrasonically processing such materials on a production basis.

Laboratory investigations during the past 20 years have demonstrated significant benefits with ultrasonic machining in terms of increased rates of material removal, decreased cutting forces, reduced tool wear, elimination of tool chatter, and altered surface finish. Most of this work involved the more readily machinable materials such as aluminum, carbon steel, austenitic stainless steel, and the like. Low-power (up to 600 watts) prototype ultrasonic systems were developed and successfully used for such applications.

The current work has extended the technology to materials that present machinability problems, particularly those used in the fabrication of Army aircraft such as the YAH-64. It involved the development of a high-power (4000 watts) ultrasonic machining system for installation on a turret lathe and preliminary evaluation with several high-strength materials designated by the Army.

Selected Materials Present Problems

Many aircraft parts made of metal alloys are difficult to machine by conventional methods. Materials such as 6Al-4V titanium alloy, hardened 17-4 PH stainless steel, and hardened 4340 and 9130 steel alloys have valuable properties such as high strength, high hardness, and good fatigue resistance, but high cutting forces are usually required and material removal rates are low. Turning operations for these materials are slow and costly. In addition, such materials tend to stick to the cutting tools and edge buildup on the tool frequently produces an undesirable surface finish.

Typical problems are encountered, for example, in the machining of large helicopter rotor head parts such as the following:

- With parts made of 6Al-4V titanium alloy, the turning speed must be slow enough so that a tool required to maintain satisfactory surface finish will not need to be changed during the final continuous cut.

- Thread milling at slow removal rates is required for external thread cutting of hardened 4130 and 4340 steel alloys. Poor surface finish is obtained with the more rapid lathe cutting of such threads.

- In straight OD turning, hardened 4130 steel requires low machining rates to avoid tearing of the surface.

Unusually difficult problems are encountered in the machining of the electroslag refined steels such as ESR 4340, which is used in drive control, flight control, and hydraulic systems. Because of the necessity for grinding to final surface finish, the turning costs may be tripled or quadrupled over the costs for the more common steel alloys. The fixturing must be more rigid because of the toughness of the material, and the turning feeds and speeds are slower. A typical material removal rate is 0.005 inch per pass to obtain the desired surface finish. Tool wear is rapid and tool breakage is frequent, and extreme care is required to prevent overheating of the material.

Such materials and operations are prime candidates for improvement, and ultrasonically assisted turning offers one avenue for such improvement.

Ultrasonic Machining Characteristics

The effectiveness of ultrasonic energy applied during lathe turning has been demonstrated in a number of investigations carried out in the United States and elsewhere.

One of the prime effects is a significant increase in material removal rate, as illustrated in Figure 1 for 2024-T3 aluminum alloy and in Figure 2 for 1018 carbon steel. These show a consistent pattern of increased cutting rate (up to fourfold) as the ultrasonic power level is increased without increasing the cutting torque.

Figure 3 shows the reduction in forces on the cutting tool with ultrasonic activation for these same materials over a range of material removal rates. Again the force reduction becomes greater as the ultrasonic power is increased. With such reduced forces, extended tool life can be anticipated.

The surface finishes obtained with ultrasonic and non-ultrasonic turning are shown in Figures 4 and 5. On the aluminum, the ultrasonic turned sections are characterized by a matte surface, while those non-ultrasonically turned are superficially shiny. In the high-magnification photographs, there appears to be less gouging and tearing of the surface with the ultrasonic assist. The minute striations of uniform regularity reflect the ultrasonic vibration cycles. Their spacing depends on the vibratory frequency in relation to the cutting speed.

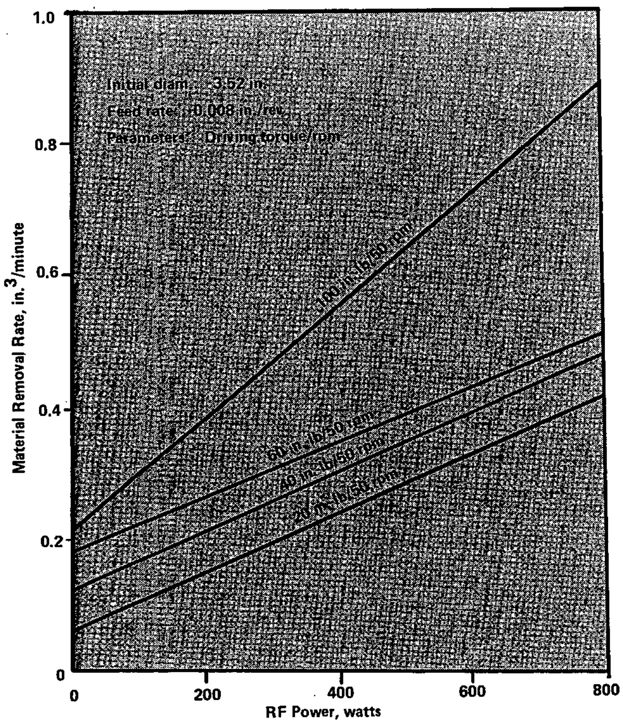


Figure 1

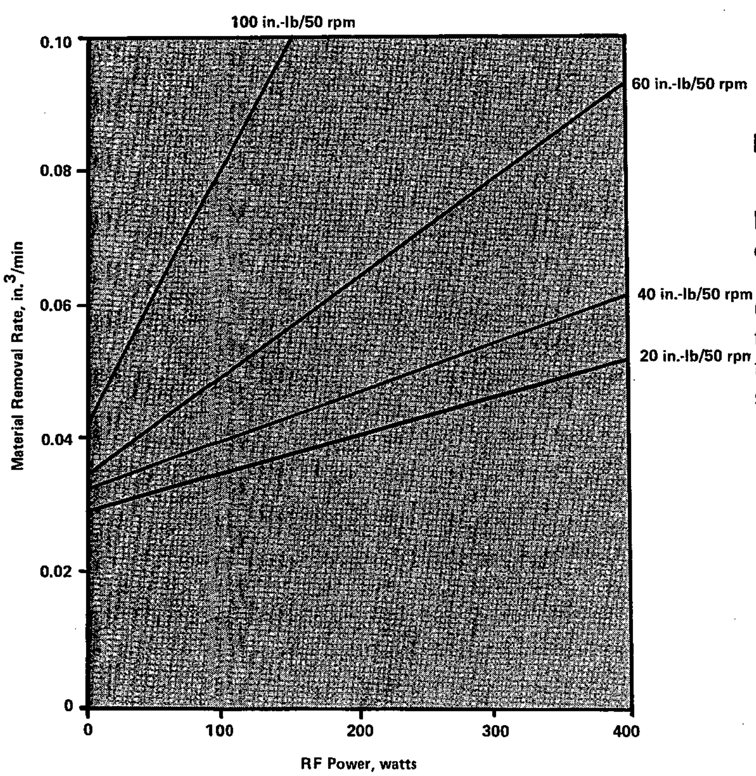


Figure 2

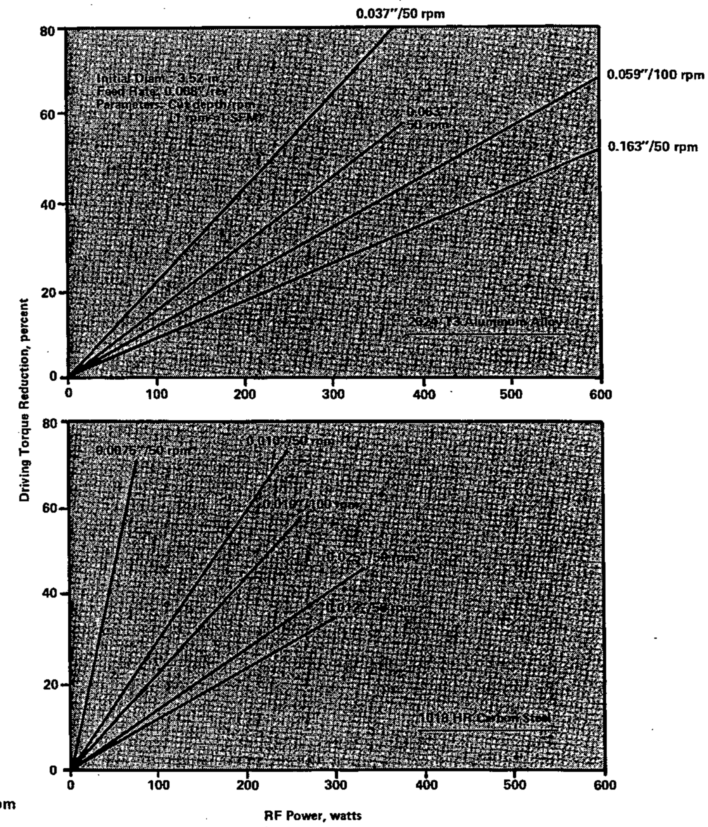


Figure 3

The striation effect is even more pronounced on the 1018 carbon steel (Figure 5). The non-ultrasonically turned section shows considerable gouging and tearing of the material.

Etched cross sections of the turned material are shown in Figure 6. Again the irregular gouging of the surface with conventional turning is apparent. By comparison, the ultrasonically turned surface is relatively smooth and there is little or no evidence of subsurface workhardening.

Visual and microscopic examination of chips obtained during machining of these materials (Figure 7) revealed, for the non-ultrasonically cut chips:

- A tight, small-radius curl
- A rough chip edge on the cut side, showing "tear-away" trails, indicating non-smooth cutting
- A generally shiny outer surface with evidence of burnishing, resulting either from the mode of cutting and tearing from the surface or from drag on the tool surface
- Erratic lateral flow and torn surfaces.

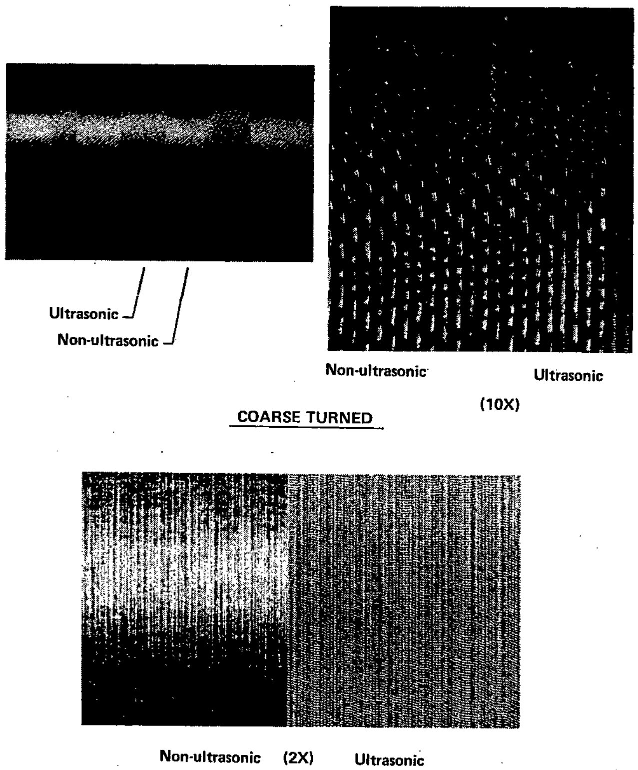


Figure 4

On the other hand, the ultrasonically cut chips were characterized by:

- A significantly greater radius for the curl
- A chip edge that was generally smooth, with evidence of a continuous cut and no indication of "tear-away"
- Outer curl surfaces of a matte finish, indicating relatively clean cutting and minimal drag along the upper surface of the tool
- Uniform lateral flow; both chip thickness and width were less than for non-ultrasonic chips.

A further observation during machining of these materials was the elimination of chatter. Under conditions that produced chatter with conventional machining, the chatter immediately ceased with ultrasonic activation and was initiated again when the ultrasonics was turned off.

Pursuant to these demonstrated benefits, prototype ultrasonic tool posts for both external and internal turning were designed and fabricated. These systems were effectively used in a pro-

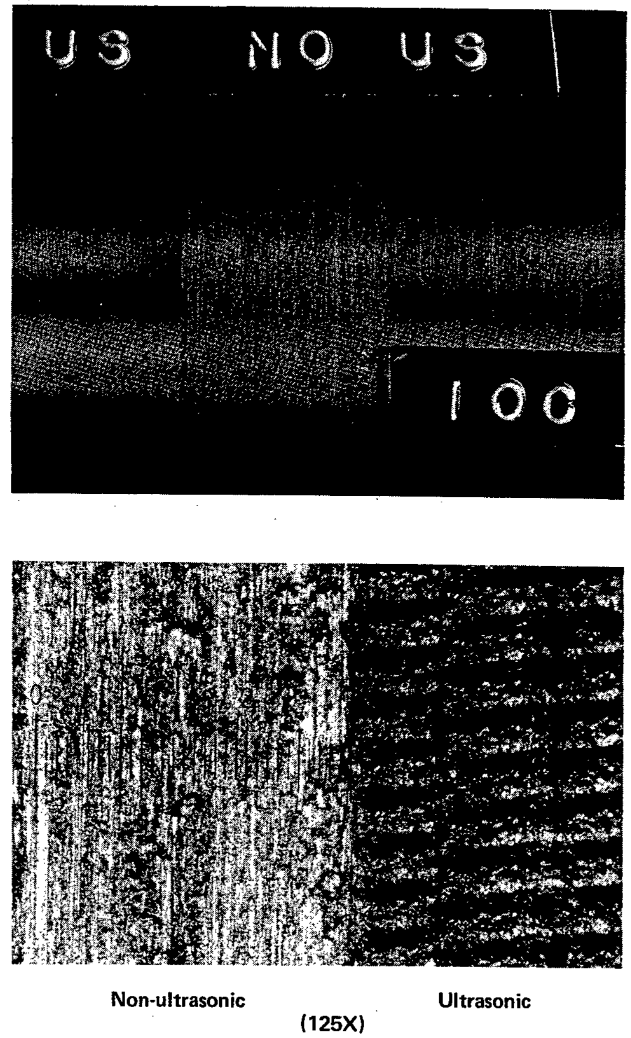


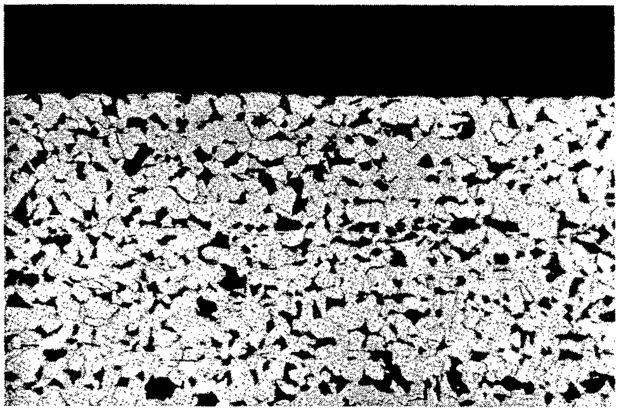
Figure 5

duction environment and confirmed the previously noted effects. The results obtained offered persuasive evidence of potential significant cost savings.

Ultrasonic Cutting Theory

It has been postulated that two major processes occur during metal cutting: (1) plastic deformation along the shear plane immediately ahead of the tool and (2) friction between the tool and the workpiece. Investigators have estimated that about three-fourths of the total energy in ordinary machining is associated with shear, while one-fourth is consumed in friction. Both friction and shear create heat, raising the temperature of the workpiece, tool, chip and lubricant.

Ultrasonic application has been demonstrated both to facilitate plastic deformation and to reduce friction. Because of these effects, metal is formed more readily under ultrasonic influence by such processes as extrusion, tube and wire drawing, rolling, draw ironing, and the like, wherein reduced forces and increas-



Ultrasonic

(100X)

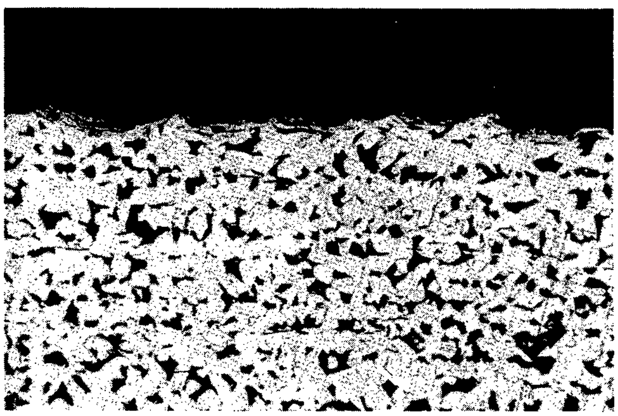


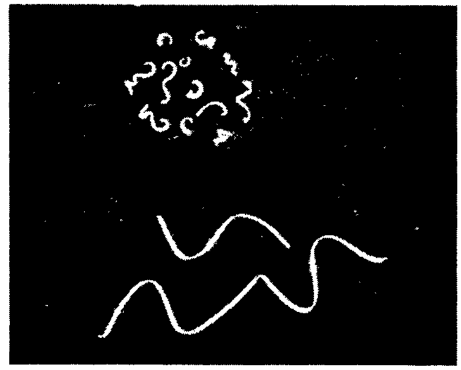
Figure 6 Non-ultrasonic

ed processing rates are characteristically obtained. These same effects are applicable in ultrasonic machining.

Numerous investigations have shown that the yield point of a metal can be significantly reduced under ultrasonic influence. Apparently, the high-frequency vibration lowers the forces required to move dislocations within the crystalline structure and to create new dislocations, so that the metal flows more readily.

In the machining process, this transient softening of the material relieves the workhardening that conventionally occurs in the area immediately ahead of the tool, so that stress distortion, fracture, and surface tearing are minimized.

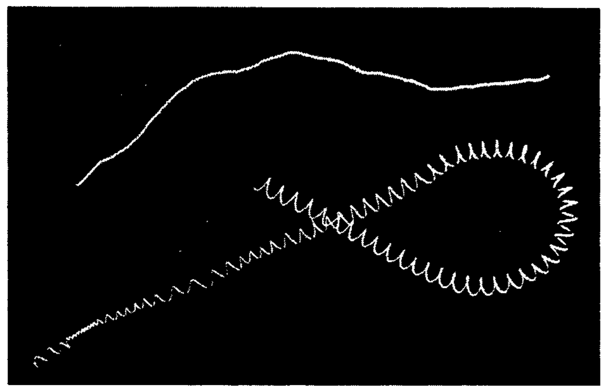
The reduced friction under ultrasonic influence is typified by greater ease in assembling components that are ordinarily difficult to assemble, as in press or interference fitting and in tightening or loosening threaded fasteners in wrenching operations. Studies made on surface layers of metals subjected to oscillating sliding friction have shown substantially less surface hardening than is obtained by unidirectional sliding. Apparently, the reciprocating action relieves a substantial amount of the distortional stress.



Non-ultrasonic

Ultrasonic

2024-T6 Aluminum Alloy



Non-ultrason

Ultrasonic

Figure 7 1018 Carbon Steel

In machining, this reduced friction can thus lead to reduced workhardening of the metal surface and reduced heat buildup in the material, leading to increased cutting rates.

Ultrasonic Lathe Cutting Systems

In any ultrasonic system that performs useful work, the flow of energy occurs as follows:

- Electrical power from a standard power line is delivered to a frequency converter which converts the 50/60 hertz power to the desired high operating frequency of the ultrasonic system.
- This high-frequency electrical power is applied to the ultrasonic transducer, which converts it to high-frequency vibratory power at the same frequency.
- The mechanical vibration is transmitted through a coupling system to the tool and thence into the material being processed.

Extensive theoretical and empirical studies have established basic design requirements for systems that will transmit the vibratory energy efficiently with minimum energy losses. Fre-

quency tuning and impedance matching throughout the system are essential.

Although there is a commonality of ultrasonic systems for various uses, each application demands consideration of the specifics for that particular process. The special considerations for ultrasonic machining include:

- Operating frequency of the system
- Mode and direction of tool excitation
- Tool and tool holder design
- Ultrasonic power level.

The effect of frequency per se is not significant in the range between about 5 kilohertz and 100 kilohertz, but practical considerations bracket a narrower range. The frequency should obviously be above the audible range, i.e., about 15 kilohertz or higher. The higher frequencies are power limited because of the smaller displacement amplitudes achievable. Frequency also dictates the physical dimensions of the transducer-coupling system required; the higher the frequency, the smaller the system. The practical range for machining is from about 15 to 30 kilohertz.

Investigations have established that the most effective vibratory mode in turning operations is in the direction of the cut, i.e.,

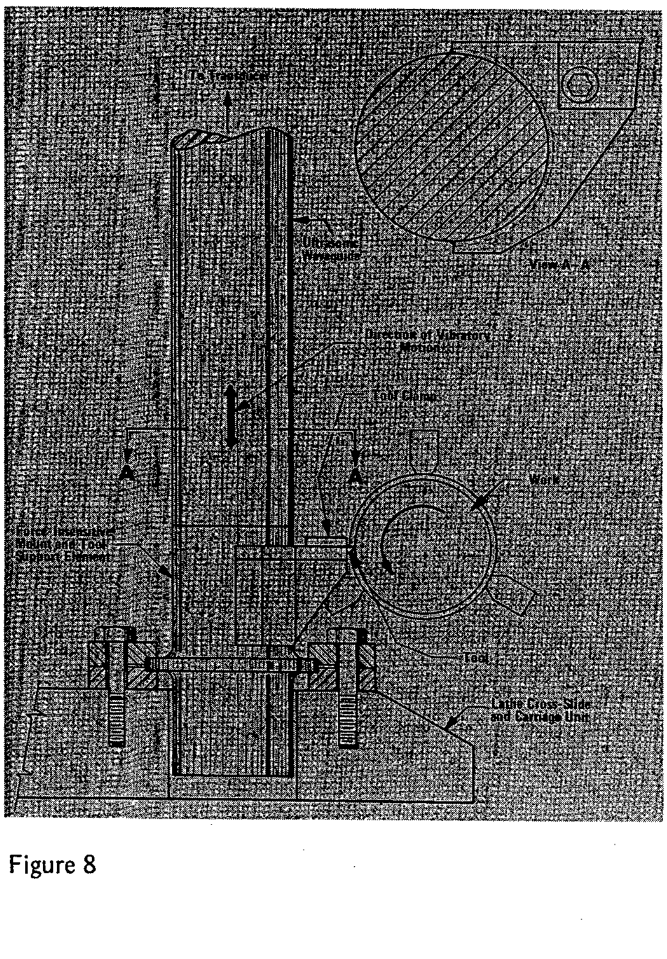


Figure 8

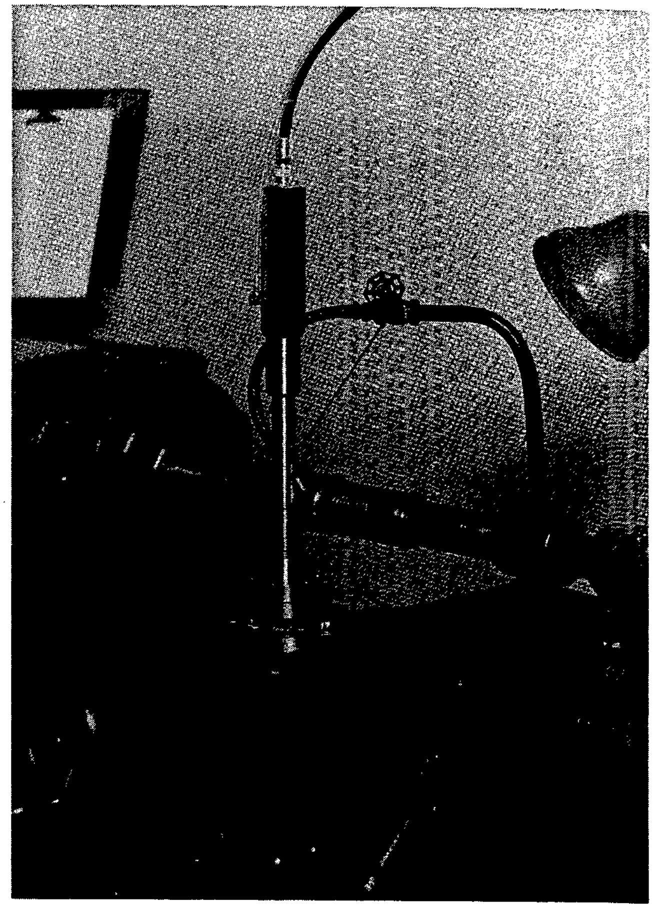


Figure 9

tangential to the rotating workpiece. Several have been evolved. A typical design is shown schematically in Figure 8. Figure 9 shows such a system mounted on a conventional engine lathe. In both cases, the tool post is clamped to the lathe cross slide and carriage unit.

The tool post, tool holder and tool must fulfill acoustic requirements since they are integral parts of the ultrasonic transmission system. These components must be sufficiently rigid to preclude unacceptable tool deflection. The tool holder, in particular, should not constitute a large mass on the system, since massive tools reduce the vibratory amplitude that can be produced at the tool. All tool posts incorporate force-insensitive mounts which ensure negligible frequency shift and negligible energy loss to the support structure under the variable static loads associated with machining.

The power rating of an ultrasonic system is usually stated in terms of high-frequency (RF) electrical power delivered from the frequency converter to the transducer, because this value is readily measurable. It is not necessarily indicative of the acoustical power delivered to the work. Some power losses occur in the ultrasonic system itself. Piezoelectrical transducers of the type used are about 90 percent efficient in converting electrical to acoustical energy. Some additional energy losses may occur at the interfaces between transducer and coupler and between the coupler and the tool, but with a properly designed acoustic system, these losses are small.

The primary consideration is transmitting acoustic energy effectively from the tool into the work. This involves matching

the acoustic terminal impedance of the ultrasonic system to the impedance of the work. If precise matching is obtained, essentially all of the applied ultrasonic power is transmitted into the work locale. A large difference in these impedance values gives rise to reflections of power at the terminus of the ultrasonic system and limits the power that can be delivered.

The impedance of an ultrasonic system can be determined by a technique involving the use of small piezoelectric type strain gages attached one-quarter wave apart on a uniform section of an ultrasonic wave guide (or coupler). The output of these devices, after appropriate amplification and oscillographic display, yields an elliptical pattern whose area is proportional to the power transmitted through the wave guide. Furthermore, the ratio of the magnitudes of major to minor axes of the ellipse represents the standing wave ratio (SWR). Ideally, this ratio should be 1.0; higher values reflect inefficiencies in ultrasonic energy delivery.

An extension of this technique permits measurement of impedance matching into the work and provides a basis for cutting tool design. With one type of tool, for example, it was found that the extent of tool overhang significantly influenced power delivery. Other tool parameters can be evaluated in a similar manner.

Program Initiated

The first task of this ultrasonic machining program involved the design, fabrication, test and evaluation of an ultrasonic system for excitation of an existing production single-point tool turret lathe and installation of this equipment at the facility of an aerospace contractor designated by the Army. The company selected was Hughes Helicopters, Culver City, CA.

Hughes Helicopters, on the basis of their experience in the fabrication of aircraft materials, provided test bars of several materials selected on the basis of machinability problems. Hughes also provided the necessary cutting tools and tool holders and supplied consultative services throughout this initial phase.

Sonobond designed, fabricated and tested the required ultrasonic array and conducted preliminary cutting trials on the selected materials. Evaluation was made of ultrasonic versus non-ultrasonic cuts, primarily in terms of rate of material removed and tool wear.

It was initially planned that the first task would be concluded with shipment of the ultrasonic system to Hughes Helicopters and installation on a turret lathe at that facility. However, the preliminary efforts indicated the advisability of modifying the ultrasonic system for more effective operation in a production environment. Shipment of the equipment was therefore delayed pending completion of such modifications.

System Designed, Assembled

The first objective of the machining program was to design and assemble an ultrasonic lathe cutting system which consisted of a tool post capable of performing single-point metal cutting operations on an existing turret lathe; and a frequency converter of sufficient capacity to supply the required high-frequency electrical energy to the ultrasonic tool post. Appropriate interfacing of the tool post with the lathe to provide maximum efficiency of energy delivery to the work was an important part of this activity.

The ultrasonic system was projected for installation on an existing lathe at the Hughes Helicopters' facility. The selected lathe was a 30 horsepower saddle type lathe with the indexing handle located on the side of the saddle and the mechanism for 90 degree rotation below the cross slide.

A lathe of this type was not available at Sonobond, and initial evaluation was carried out on an existing 7 horsepower engine and diemaker lathe. Integration of the ultrasonic system with both lathes presented no major problems.

An effective ultrasonic tool post for a turret type installation basically consisted of an ultrasonic transducer to generate the high-frequency vibration and an acoustic coupling system to transmit the vibratory energy to the tool holder and tool insert.

Initially, consideration was given to the operating frequency and required power rating of the ultrasonic system. The frequency selected was 15 kilohertz, which would provide maximum amplitude of vibration within an acceptable noise level.

Past experience had shown that the ultrasonic power level, to have an appreciable effect in ultrasonic cutting, should be about 15 to 20 percent of the mechanical power level required to perform the task. Based on this empirical ratio, the ultrasonic system power capacity for a 30 horsepower lathe should be within the range of 3375 to 4500 watts. For the lathe of 7 horsepower capacity, the required ultrasonic power would be within the range of about 800 to 1050 watts.

Accordingly, it was decided to design the system for operation at 15 kilohertz and 4000 watts. An ultrasonic transducer and matching frequency converter at these ratings are standardly used in Sonobond's largest commercial ultrasonic spot welder, so these component designs were immediately available.

The standard 4000-watt piezoelectric transducer (Figure 10) consisted of disks of lead zirconate titanate polarized in the thickness mode, incorporated in a rugged assembly of the tension shell type with a bias compressive stress on the ceramic disks to preclude failure under dynamic stress. Cooling channels permitted cooling air flow through the assemblies to prevent overheating and depolarization of the transducer elements.

A coupler or wave guide to operate at the 15 kilohertz design frequency was designed and fabricated. This component incorporated a force-insensitive mount to isolate the system from the lathe bed.

Figure 11 shows schematically the final design of the ultrasonic tool post that was mounted on the 7 horsepower lathe.

The frequency converter was a hybrid-junction transistorized solid-state device consisting of an amplifier and oscillators to supply the high-frequency electrical power to the transducer. The output frequency of the system could be fine tuned to precisely match the operating frequency of the transducer coupling system.

For mounting of the ultrasonic system on the turret lathe, an unfinished forging of standard turret was obtained. The upper

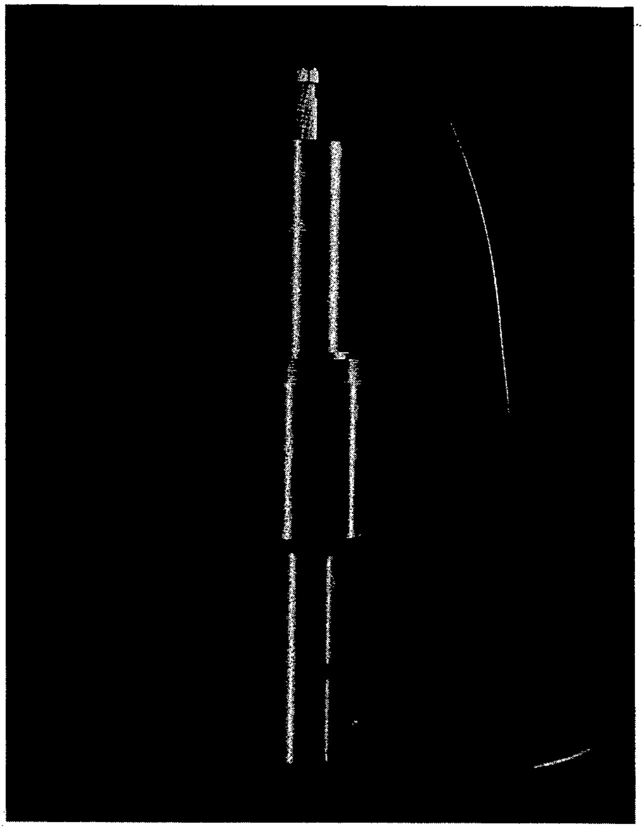


Figure 10

part of this forging was removed and the lower part was machined to provide a proper fit.

Tool Holders and Inserts

Representative tool holders and tool inserts were selected and supplied by Hughes Helicopters. Tool inserts were of a type and material frequently utilized in machining problem materials—tungsten carbide base with 10% cobalt.

Materials Selected Jointly

The basic materials for evaluation of ultrasonic cutting were selected by joint consultation involving the Army, Hughes Helicopters, and Sonobond Corporation. These included:

- 9310 Low-carbon steel
- 4340 Medium-carbon steel
- 17-4 PH Stainless stell
- ESR 4340 Electroslag refined steel
- 6Al-4V Titanium alloy.

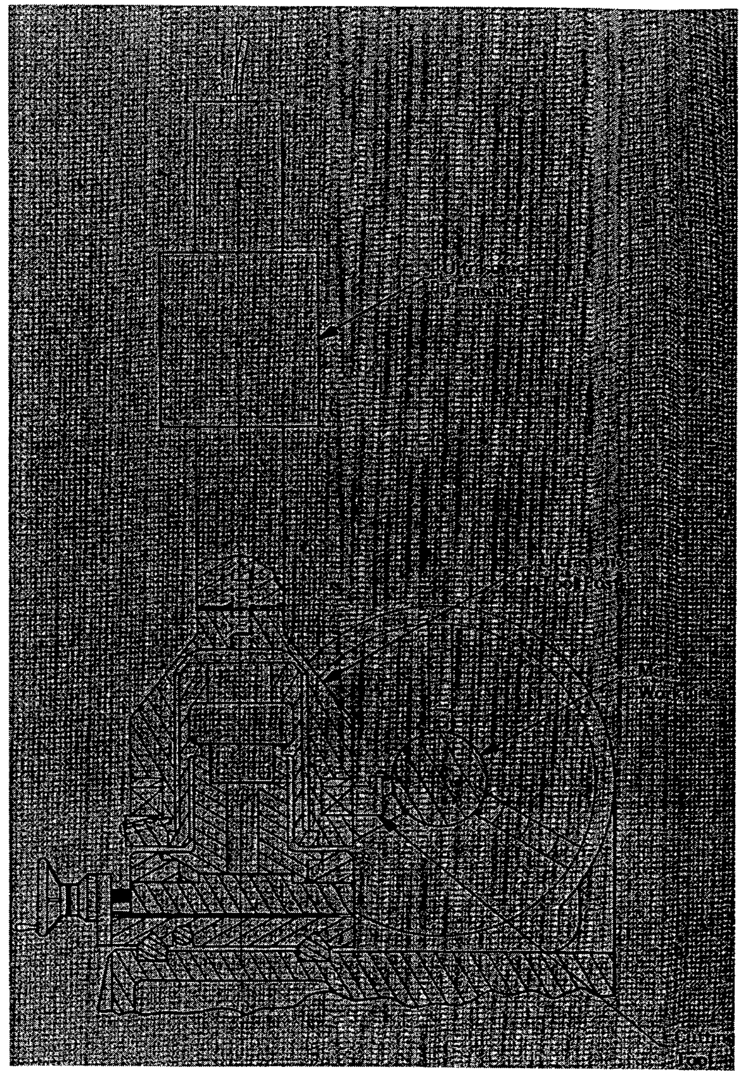


Figure 11

These materials were recognized to present machining problems, especially in terms of slow material removal rate, rapid tool wear, or difficulties in attaining acceptable surface finish.

Bars of these materials, usually 3 inches in diameter by 15 inches long, were supplied by Hughes Helicopters each in the heat-treat condition characteristic of the state in which it is used in fabrication of aircraft components. For example, Ti-6Al-4V alloy was supplied in the annealed condition because it is generally used in this state. The steel alloys were all heat treated to the desired hardness.

Additional materials were supplied by other companies interested in ultrasonic machining and it was agreed that the data should be reported herein. Pratt & Whitney Aircraft Group supplied some bars of titanium/aluminum alloys—Ti-Al and Ti-3Al—which generally are not easily machinable. Westinghouse Electric Company, Turbine Components Plant, provided bars of Refractaloy 26, a material used for turbine shafts. This material is capable of being machined, but cutting tool wear is excessive.

Data Recorded, Compared

Bars of the material to be machined were turned on the lathe under selected cutting conditions both with and without ultrasonic application. Baseline data for conventional (non-ultrasonic) cutting of some of these materials were obtained for 9310 steel, 4340 steel, 17-4 PH steel and 6Al-4V titanium alloy. For the remaining materials, cutting conditions were selected empirically or at the recommendation of the material suppliers.

Data were recorded for the cutting speed in surface feet per minute (SFM), calculated from rod diameterand rotational speed in revolutions per minute (RPM), feed rate in inches per revolution (ipr) and depth of cut in inches. These data were used to calculate the rate of material removal in cubic inches per minute. Ultrasonic power level was also recorded in all runs. For evaluation of surface finish, the cut surfaces were scanned with a Brush Surfindicator.

General Observations

The results of these evaluations of ultrasonic machining generally confirmed the results obtained earlier with more readily machinable materials. Non-ultrasonic cutting was frequently characterized by tool chatter, which was virtually eliminated with ultrasonic activation. This phenomenon was audibly apparent whenever ultrasonics was turned on or off during a particularly heavy cut.

The chips from non-ultrasonic cutting were sometimes blue or burnished: no such discoloration was apparent with the ultrasonically cut chips, indicating the absence of detrimental overheating of the tool and the work material.

Ultrasonics substantially accelerated the rate of material removal with these difficult-to-machine materials, and tool wear was reduced.

Breakage of the carbide tool insert occurred under certain cutting conditions, apparently because the capability of the 7 horsepower lathe was being exceeded. Such breakage usually occurred more readily with the non-ultrasonic than with the ultrasonic cutting. In some instances, the tool broke instantaneously when the ultrasonic system was turned off during a cut. This suggests that the tool loads were lower with ultrasonic activation.

Surface Finish Inconclusive

Controlled experiments were made with four materials to evaluate the ultrasonic effect on surface finish. Cuts were made at slow material removal rates characteristic of finish cuts. These experiments were carried out with and without lubricant/coolant, without ultrasonics and at ultrasonic power levels of 1000 and 2000 watts.

The data show no consistent pattern of an ultrasonic effect on surface finish. In some instances, the surface finish was smoother and in others it was rougher with ultrasonic application. There appeared to be a trend toward improved finish when the coolant was used at 1000 watts ultrasonic power, as if the vibratory energy aided in pumping the liquid into and out of the cut, but the ultrasonics did not always effect improvement.

Surface finish data obtained sporadically on rough machine cuts likewise showed inconsistencies that could not be explained. This effect requires further evaluation after equipment modification.

Material Removal Rates

One of the major demonstrated effects of the ultrasonic assist to machining was the substantially increased rates of material removal. It was possible to increase both the cutting speed and the depth of the cut.

9310 Steel. With this material, the rate of metal removal was increased from 14.04 cubic inches per minute, as recommended for conventional cutting, to 24.75 cubic inches per minute with ultrasonics, an improvement factor of 1.76. Although tool breakage occurred at some of the higher removal rates, this was attributed to limitations of the lathe and not the ultrasonic system.

4340 Steel. Good cuts on the 4340 steel were obtained at removal rates up to 15.47 cubic inches per minute, compared to a recommended rate of 7.56 cubic inches per minute. The improvement factor here was 2.05.

17-4 PH Stainless Steel. A substantially greater effect was obtained with this material. A low removal rate of 3.42 cubic inches per minute was recommended. Ultrasonics permitted cutting at rates up to 25.02 cubic inches per minute, an improvement factor of 7.32. Stalling of the lathe became a factor at the higher cutting rates.

ESR 4340 Steel. Baseline data for this material was not available. Accordingly, several cuts were made without ultrasonics. Very low removal rates were obtained—less than 1 cubic inch per minute—and these were limited by rapid tool wear. When the ultrasonics was turned on, the improved cutting was immediately apparent and good cuts were obtained at rates up to 4.12 cubic inches per minute.

6Al-4V Titanium Alloy. Recommended machine settings specified a material removal rate of 4.86 cubic inches per minute. With ultrasonics, rates up to 15.14 cubic inches per minute were possible, an improvement factor of 3.17.

Titanium/Aluminum Alloys. These alloys were reported to be very difficult to machine by conventioinal methods and were stated to be subject to severe tearing and surface damage. Good cuts were obtained ultrasonically at a rate of 1.21 cubic inches per minute.

Tool Wear

Some of the materials investigated, particularly ESR 4340 steel and Refractaloy 26, reportedly induce rapid tool wear and/or breakage in conventional machining. A few experiments were oriented to determining the ultrasonic effect on this phenomenon.

In almost every instance, ultrasonic application substantially increased tool life. With the Refractaloy, for example, under one set of conditions the tool broke after 2.5 inches of conventional cutting and after 10.5 inches of ultrasonic cutting. With the maximum removal rate used, 3.92 cubic inches per minute, the tool in conventiional cutting was worn 0.07 inch after 4.8 inches of

cutting, while that used in ultrasonic cutting was worn only 0.03 inch after 5.1 inches of cutting.

Even greater effect was obtained with ESR 4340. After 0.3 inch of conventional cutting, the tool burned and broke. In ultrasonic cutting, the tool showed only 0.014 inch of wear after a 16.5 inch cut.

Chip Characteristics

Comparison was made of the chips removed from the metal with ultrasonic and non-ultrasonic turning. Typical chips obtained under both conditions are shown in Figure 12. In all instances, the ultrasonic chips were characterized by a much larger curl radius, suggesting that less strain was induced in the chip as a result of ultrasonic activation.

A metallographic analysis of representative chips produced with and without ultrasonic assist was made by Professor Kenneth J. Trigger of the Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, IL.

Chip samples of 4340 steel were examined microscopically and measurements made on the free surface, of 4340 steel, i.e., the side opposite the tool-chip interface. The free surface of a

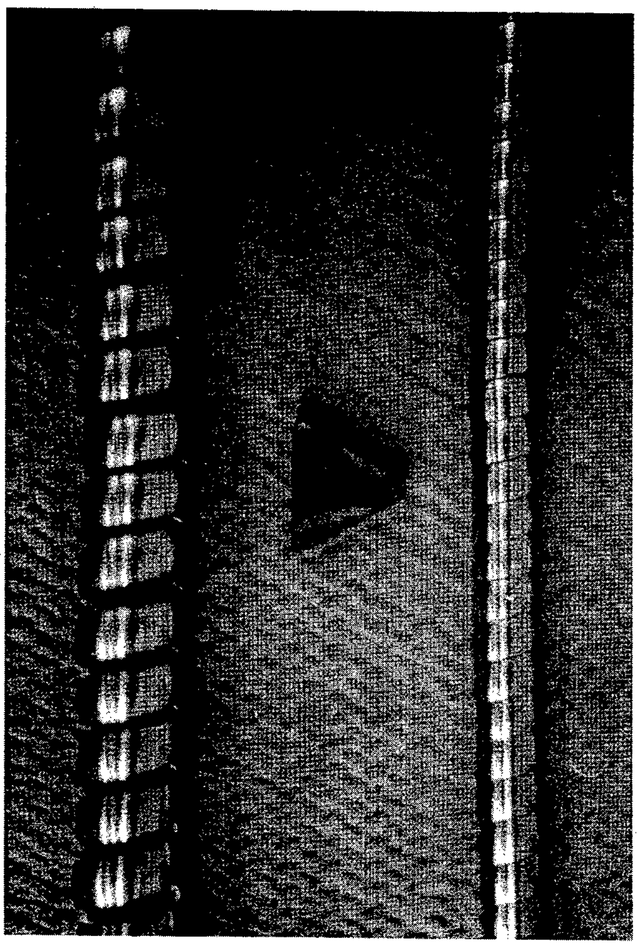


Figure 12 Ultrasonic Non-ultrasonic

continuous chip (not a so-called brittle chip as in cast iron) is typically a lamella-like array. The spacing of the lamella is dependent upon the shear behavior of the tool, the tool geometry, and, especially, the tool-chip friction at the interface. In this comparison, the only variable was the tool-chip formation.

The chips were examined with a low-power microscope equipped with a filar micrometer eyepiece, giving an overall magnification of approximately 20X, and the lamella spacings were measured. Five to eight measurements, each involving a minimum of 20 lamella, were made on representative samples for each test condition. In addition, the average chip thickness from the tool interface to the midpoint of the free surface was measured. The results were as follows:

- With Ultrasonic Assist
  - Lamella spacing: 0.0067—0.0075 inch
  - Average chip thickness: 0.012—0.013 inch
- Without Ultrasonic Assist
  - Lamella spacing: 0.0085—0.0095 inch
  - Average chip thickness: Approximately the same as above, but lamella plate projections were higher and less regular.

Chip samples were tested for microhardness with a 136-degree square base diamond pyramid indenter at 2 kilograms load. The higher chip body hardness in the non-ultrasonic chip is probably due to the higher chip strain as a consequence of high tool-chip friction.

Results Show Positive Benefits

These preliminary machining studies indicated positive and significant effects of the ultrasonic assist in terms of increased material removal rates and reduced tool wear. The equipment and experimentation satisfied the basic requirements of the contract. However, the work also indicated the need for further modification and refinement of the ultrasonic equipment for evaluation in a production environment, as outlined:

(1) The ultrasonic equipment should be modified and refined for evaluation on a turret lathe in a production environment; such modifications should consist of

   (a) Redesign of the ultrasonic tool post to provide improved, positive tool retention

   (b) Installation of a power interlocking system to provide automatic activation of ultrasonic power when the cutting load is initiated

   (c) Development of feedback circuitry that will match the ultrasonic power delivery to the tool load in order to maximize impedance matching at the tool/work interface under varying machining conditions.

(2) It is recommended that a production turret lathe be equipped with the modified ultrasonic system for detailed evaluation of the effectiveness of ultrasonically assisted turning under production conditions.

Brief Status Reports

Project 3010. Millimeter-Wave Sources for 60, 94, and 140 GHz. Analysis of pilot production run of 14 lots of D-band, V-band, and W-band silicon impatts indicate an overall yield of 25 percent. Diode cost is reduced from $400 to $60. MMT modulator is unstable. TRW modulator will be used instead. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3011. Indium-Phosphide Gunn Devices. The two EPI layer process yield is 90 percent. Although process problems still exist, the INP gunn diodes are surpassing the requirements of the MMT at 56 and 94 GHz. The thinned integral heat sink is still problematic. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3023. Tubular Plasma Panel. An industry demonstration of the manufacturing facility was held. A no-cost extension of one year was granted to Norden. At that time, Norden will deliver a mifass panel for use in a display simulator. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3026. High Pressure Oxide IC Process. The revision of the furnace improved performance at low pressure/high temperature. At 1000 psi, convective heat loss prevented attainment of 750 C. Autoclave Engineers, Inc. will study requirements to complete. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3501. Third Generation Photocathode on Fiber-Optic Faceplate. ITT Roanoke is reevaluating processing procedures because of cosmetic discrepancies on 25mm 0.9 micron 3rd generation photocathodes on fiber-optic faceplates. Bonding problems were resolved. May go to metal organic vapor phase epitaxy growth. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3505. High Contrast CRT Phosphor Deposition and Sealing. Hughes has delivered confirmatory samples including one operable CRT and several multi-phosphor faceplates. Completion of fabrication facilities in compliance with OSHA standards has resulted in unanticipated expenditures. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3505. High Contrast CRT Phosphor Deposition and Sealing—Phase II. Additional confirmatory CRTs are complete under Phase I. Descoping Phase I for confirmatory CRT samples is being discussed with procurement. Effort on Phase II is currently low level. For more information, contact Joseph Key, ERAD—COM, (201) 544-4258.

Project 5010. Bonded Grid Electron Gun. Boron nitride grid blocks from Union Carbide had wrong curvature radius. They made another lot. Experiments for attaching grid blocks to cathode are on-going. J.K. Lasers is experimenting with the required laser milling. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5019. Laser-Cut Substrates for Microwave Tubes. 15 S-band and 15 C-band anode circuits have been fabricated and successfully passed testing. Copper-tungsten ground plane thermal expansion problem was analyzed metallurgically and solved. Laser Services, Inc. uses well known CO2 laser cutting on BEO. Phase II objective is to incorporate the new anode circuit into CFA tubes. Confirmatory samples of 2 C-band CFA and 2 S-band CFA to be delivered. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5041. Millimeter Wave Mixers and Arrays. The contract has been descoped to delete the 140 GHz mixer because of unresolvable problems. Ten each of pilot run samples at 56 and 94 GHz will be delivered. This mixer design is generic and can be used in many missile seekers and communications sets. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5107. 94 GHz Pulsed Power Combiner. Work was redirected to a solid state amplifier for Milstar, a $500 million program. This low noise amplifier for satellite communications will be made using standard litho techniques rather than electron beam writing. Will automate impatt amp production. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5109. Precision Low-Cost Surface Acoustic Wave Delay Lines—UHF Application. TRW is fabricating 403 KHz and 506 MHz saw delay lines. Phase I engine samples were subjected to mechanical, environmental and electrical tests. Deficiencies will be corrected prior to submission of 2nd engine sample lot. Major end item is AN/TMQ-31. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 6350-2200. Automated Identification, Sizing, and Counting of Particulate Contamination. The technical work for this project has been completed. The technical report has been submitted. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 5071-80. Computer-Aided Test Planning. The CAT plan is dually operational as the central tool for producing USATTC detailed test plans. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-100. Automatic Particle Contamination Measure in Hydraulic Oil. After trying diesel fuel, lube oil, hydraulic fluid gives the most consistent results and will be used as the base oil for dilution of small samples of contaminant oil. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-57. General Purpose BIT Slice Microcomputer. The general purpose BIT-slice microcomputer interface is complete and resides in the Data General Eclipse SL250 minicomputer and Data General Eclipse SL130 minicomputer. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 7119. Non-Destructive Evaluation Technique for Composite Structures. Part II of the handbook on physiochemical characterization techniques was completed. Reviews of liquid chromatography, real time thermography, ultrasonic, and acoustic emission QC techniques, and of the QC of the AH-1 blade are in process. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7197. Fabrication of Integral Rotors by Joining. Machining of rotors for engine testing complete. Crack growth data generation for all CAP and HIP material to substantiate rotor life in accordance with inspection guidelines in progress. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7202. Application of Thermoplastics to Helicopter Secondary Structures. Final assembly of the prototype doors was completed. Results of structural tests demonstrated good structural properties. Implementation plans consist of flight testing of the CH-47 engine access door assembly pending safety-of-flight release. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7288. MMT Determination Optimal Curing Conditions. Prepreg E-glass and S-2 glass/epoxy formulations were autoclave cured to under, standard, and postcure conditions. Specimens from each condition are being tested mechanically and chemically (fourier transformation infrared spectroscopy). For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7298. High Temperature Vacuum Carburizing. Initial process development has been completed. Metallurgical examinations were performed on three test 9310 steel slugs. Carburization requirements were satisfactory, but microstructural property results dictated changes to the carburization process. Approximately 75 percent of the 9310 steel gear roller specimens have been tested. Metallurgical evaluation revealed unacceptable microstructural characteristics. New test samples at different heat treatment parameters have been prepared. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7322. Low-Cost Transpiration-Cooled Combustor Liner. Work continuing on schedule. 4000 amp pulse rectifier has been purchased by DDA. Various parameters which affect etching rates and quality of pattern are being evaluated to speed fabrication and reduce cost. Sheets placed in metal bag improved quality. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7340. Composite Main Rotor Blade. Work was conducted to resolve the HHI vibration problem. A resolution of the problem was not achieved before MT funding was expended. A draft final technical report has been prepared. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7371. Integrated Blade Inspection System (IBIS). Work continued on the XIM portion of IBIS. Acquisition and fabrication on some XIM hardware has been accomplished. Development of computational software continues; it is used in detecting and analyzing flaws. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7376. Automated Inspection and Precision Grinding of SB Gears. Final inspection process has been demonstrated. In-process inspection process development is under way. Originally specified computer hardware was insufficient and a larger unit is being procured. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7382. Low-Cost Composite Main Rotor Blade for the UH-60A. Fabrication of the 5 short spar sections has been completed, and ballistic and process verification testing has been initiated. Contract is being modified to eliminate cocured blade process in favor of a precured spar concept.

Project 8190. Improved Cutter Life, T-700 Computer Blisk/Impeller Milling Operations. Statistically designed experiments have identified a potentially optimum combination of tool

material and geometry and feeds and speeds. Verification testing will be conducted. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 8192. Turbine Engine Productivity Improvement. Project is proceeding on schedule with no slippage anticipated. Operational sorting network system used for group classification. Metalmats system used for computer generation of routings and time standards. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 3054. Production Methods for Multi-Layer Folded Circuits. Hughes completed testing rigid-flex circuit board samples with positive results. Board fabrication now delayed due to eprom reprogramming. Goals are to automate rigid-flex board manufacture, select compatible materials, and create process specifications. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3057. High Stability Vibration Resistant Quartz Crystals. Frequency Electronics is building a pilot line for 5 MHz SC cut quartz crystals in ceramic flatpacks. Automatic X-ray, cut and grind angle correction, and parallel gap welding were developed. Bake and seal stage for 48 units was designed. Plating tested ok. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3068. Increase Producibility of Varactors and Pin Diodes. GaAs varactor chip design requirements have been finalized. Epitaxial dopant curve was developed. Silicon pin diode materials were ordered, process flow sheet was completed and the mesa etches are characterized. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3073. Tactical Graphics Display Panel. GTE Corp. experienced row shorting problems in fabricating 10 x 12.5 in. thin film electroluminescent display panels. Diagnostic tests are under way. Drive electronics almost complete and testing has begun. Pilot line producing 10 panels a day is goal. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3083. MM Wave Communications Front End Module (CFEM). A contract was awarded to establish a capability to build integrated mm wave front end transmit-receive modules. Will include transmitter source, bite test coupler, transmitter power attenuator, filter, mixer, source and preamp. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 9898. Ruggedized Tactical Fiber-Optic Cables. Pilot production of the military fiber-optic cables is currently ongoing. Contractual agreements on device specification have been made. A full 6-part military specification was jointly generated. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 1042. Production of Composite Radome Structures. The production rate of the roving saturation equipment was increased. Process plans and tooling designs were established. Tooling was fabricated. Funds will be reprogrammed to also award a contract for production proveout of single layer design. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1051. Replacement of Asbestos in Rocket Motor Insulations. Task 1 of the four contractor efforts to find replacement formulations for composite propellant grain inhibitors, smokeless insulators, and flexible rocket motor insulator were successful. The contracts for Task 2 for 3 of the 4 contractor efforts have been placed. The contract for the fourth effort is in process. Task 2 work consists of scaling up the processes for the candidate materials to full scale components. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1060. Electrical Test and Screening of Chips. Test system mechanical specification with rotating arm was prepared. Planned computer control architecture supports four functions: pattern recognition, host simulator, direct chip probe/testing controller and workstation controller. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1075. Electronics Computer-Aided Manufacturing (ECAM). Battelle developed a master plan defining the MT projects needed to realize a computer-aided manufacturing capability. Automation and CAD/CAM technologies were addressed. Descriptions of future manufacturing projects were developed and prioritized. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1086. Cobalt Replacement in Maraging Steel Rocket Motor Components. This Phase 2 effort is essentially complete. A final report covering this phase has been drafted and will be distributed. Phase 3 effort is just getting started. Milestone chart is being prepared pending contract finalization. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1108. RF and Laser Hardening of Missile Domes. Battelle sputtered an indium tin oxide coating onto 60 domes to evaluate its laser energy

shielding capability. Also, a fine copper and nickel grid was blated onto the inside of domes to give them radio energy shielding. A demo was held for industry. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1109. Robotized Wire Harness Assembly System. The subsystem specification documentation was officially released into the Boeing Documentation System. This document includes both hardware requirements specification and software design specification hardware design equipment specification. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1121. Missile Manufacturing Productivity Improvement Program. A scope of work was prepared and meetings held with Navy and Air Force. A contract will be negotiated with Martin Marietta to analyze their subcontractors manufacturing planning to find productivity and business system improvements. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1126. Wound Elastomer Insulator Process. Case bond aging tests continued. Adhesion tests of the 4 wound elastomeric insulator candidate formulas to the molding formula for premolds were conducted. Design verification studies continued. Hercules received the authority to proceed with Task II (FY 83 funding) on May 6, 1983. Hercules recommended that integral thrust reversal adapters are feasible with the wound elastomeric insulator program. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project3411. Non-Planar Printed Circuit Boards. Assembly of 5 antennas is in progress by Multimetrics Inc. The trimming fixture required for the balon assembly has been utilized to fabricate a series of test spirals. These will be tested for gain uniformity, pattern shape and axial ratio. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5005. Computer-Aided Design for Cold Forged Gears (Phase I). The data section of the computer program that will handle gear geometries. The drawing routines were modified to accommodate helical gear geometry. The appendices dealing with various analysis have been completed. (Phase II): Two gears (one spur and one helical) have been chosen for use in the forging trials. The gear drawings are being evaluated and will be sent to TACOM for approval. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5082. Flexible Machining System, Pilot Line for TCV Components. Phase I is technically complete. A FMS manual with supporting software has been developed. Phase II also is technically complete. Contract consulting support was provided to four installations to determine the feasibility and configuration of FMS. The last phase of a five phase program will provide support to DOD contractors who are planning to install and/or optimize FMS. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5083. Upscaling of Advanced Powdered Metallurgy Processes-PH 3. Seven No. 6 AGT 1500 engine accessory gears have been forged. Complete die fill has been obtained and quality appears excellent. TRW will forge a gear for the M2/M3 instead of another ACT 1500 engine accessory gear. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5090. Improved and Cost Effective Machining Technology (Phase IV). Data collection nearly complete. Results submitted on the HZB301 experimental armor. (Phase V): contractor has begun visits to vehicle/component contractors and is selecting possible candidate components for non-traditional machining processes. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5091. Heavy Aluminum Plate Fabrication (Phase I). Aluminum armor plates and welding electrodes ordered and received. Holding fixtures and weld joints designed. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6011. Springs From Fiber/Plastic Composites. Lab testing has been conducted to verify the adequacy of the design for the rear leaf spring set. A high stress rate was used to minimize the test duration. Ten sets of springs have been made. Front spring assembly was redesigned for composite materials and manufacturing processes. Dies were designed and fabricated. All required material was procured. Fabrication was deferred until testing was completed for the rear leaf spring. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6028. Production Quality Control by Automated Inspection Equipment. A new TDP for on-line evaluation of the AIDS was prepared and the contract was awarded. Control software for the 6V53 engine was generated by the contractor. Hardware evaluation has begun. The ABS compression test will be evaluated in the latter part of '83. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6038. High Deposition Welding. Flux core welding, H-plates welded. Submerged arc welding parameters established. Narrow gap welding equipment being adjusted. Plasma M16 equipment being selected. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6054. Advanced Metrology Systems Integration. The state-of-the-art metrology system survey was completed. The needs analysis and SOA report are in process. Function models of current factory practice as revealed by industry surveys have been reviewed and approved. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6089. Abrams Tank Plant—Technical Modification Program. A preliminary scope of work has been developed for Phase I on the IPI. This IPI will encompass four plants, Detroit ATP, Lima ATP, Scranton and Sterling Heights. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6098. Production of Special Armor Steel. Steel produced meets the established requirements of texture and hardness. Preparations have been made to roll half inch thick and less. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6099. Manufacturing Methods for Specialized Armor Materials. AMMRC, ARRADCOM, and PMB have initiated activity in the areas of materials, processes and facilities toward realizing the program objective. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 7580. Pilot Automated Shop Loading and Control System—CAM. Final implementation actions continuing during the period. The project is technically complete. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7707. Automated Process Control for Machining. Computer procedures for determining economical turning operations were established and demonstrated to Rock Island Arsenal personnel. Computer procedures for determining economical drilling and milling operations were designed and developed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7724. Group Technology of Weapon Systems (CAM). A variant process planning system was developed. Implementation is scheduled. Hardware to support solid modeling was installed. A GT scheduling system was developed. A microprocessor to support this program has been ordered. A literature search was conducted. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7730. Manufacture of Split Ring Breech Seals. Design changes for automated abrasive saw have been sent to procurement. Test pieces for kinking machine tests are being manufactured. Polishing fixture has been manufactured. Specification changes have been proposed to simplify presently defined equipment. Test piece for kinking equipment tests are being manufactured. Interchangeable jaws and dual purpose table are being designed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7753. Noise Suppressor for Powder Type Recoil Mechanism Test Machine. The noise suppressor is being modified. These modifications include extensive repair welding. A large instrumentation port was added. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7966. Manufacture of Tritium Powered Radioluminous Lamps. Testing and analysis of tritium lamp samples has been completed. Results confirm adequacy of current production methods. Process controls have been identified. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8102. Powder Metallurgy Forgings Weapons Components. A contract to establish production parameters for manufacturing split ring components has been negotiated. Various non-destructive testing techniques are being evaluated for applicability to the net shape split rings. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8103. High Velocity Machining. Project parameters are being finalized utilizing results of advanced machining research program funded by DARPA. Equipment at Mechanicsburg, PA has been identified as being potentially applicable to this program. Instrumentation is available to perform force measurements after the equipment has been installed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8120. Adaptive Control Technology (CAM). A detailed specification to retrofit a cylindrical grinder is being prepared. If possible an existing machine tool will be used. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8243. Computer Control for Electrodeposition Systems. Definitions of input/output requirements for the new chrome plating facility

have been completed. Definition of normal component and alarm/ annunciator conditions for each state of the 120 mm/8 inch production plating facility is completed. A diagnostics simulator has been defined and acquisition of components initiated. For more information contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8244. Optimize the Heat Treatment of Rotary Forge Tubes. An analysis is being conducted of several parameters to determine their effect on mechanical properties of tubes. Differences between two tube heats is being analyzed by checking chemistry, hardenability, mechanical properties, and inclusions. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8245. Application of Erosion Resistant Low Contraction Chromium Plate. The purchase of a larger rectifier has been approved. Experiments to deposit LC chromium with a limited capacity of amperage were conducted on M68 tubes to obtain plating parameters. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 1701. Bulk Transfer of Chemical Materials. Completed collection of health and safety data. Continued analysis of current and proposed handling procedures and equipment survey. Initiated contract with AE firm to aid in facility layout. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4062. Automatic Manufacture System for Mortar Increment Containers. Project manufacture has been intensified to accelerate the equipment acceptance test schedules and to minimize the impact of the cost-to-complete proposals submitted by ESD. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4273. Automated Production of Stick Propellant. Review of die design, extrusion rate, and dry down data was continued. A pilot test line arrangement using a 4-inch press was laid out and approved to allow various cutting and handling configurations. Preliminary hazards analysis conducted. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4312. Anti-Armor Cluster Munition Production Explosive Invection. The redesign of the production prototype injection molding unit for CEMS was completed. A bid package for procuring a molding unit was prepared. Invitation for bids were issued and a vendor was selected. The injector unit is being fabricated. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4533. Lova Propellant Processing. NOS has drawn up an in-process hazards assessment test matrix. NOS initiated a literature search to compile and analyze existing in-process hazards data for lova run materials, primarily RDX and NC. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4534. XM855 Bullet Conversion of SCAMP Equipment. Cost growth requested to increase the contract value by 135K to incorporate changes requested by AMCCOM and Lake City AAP for the tip I.D. application on a SCAMP load and assemble submodule, DCAA concurred with the requested cost growth. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4540. $CaCO_3$ Coating of 7.62 mm Ball Propellant. With the concordance of PBM, this project is now at Badger AAP instead of Olin, St. Marks, Fl., as originally planned. A revised SOW submitted in May and a contract awarded to Badger in June. SOW reduced to reflect reduction of funding. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 6599. Electro-Optical Inspection of Artillery Projectile Optical Cavity. All defect detecting electronics circuitry has been checked for proper operation and adjustments optimized. The only circuit still requiring adjustment is one that inhibits false reject signals. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 3592. Improved Graphite Reinforcement. The carbonization step and pre-graphitization step were optimized. A heating rate of 400 C produced the highest strength and modulus and the optimum graphitization temperature was found to be 1400 C. For more information, contact Sid Levine, BRDE, (703) 664-5374.

Project 3759. Kevlar Cable Reinforcement for Military Bridges. This effort is complete. It established a continuous tape lay-up method suitable for production of various width, length or load capacity tensile elements. 45 elements were tested statically and dynamically with complete satisfaction. For more information, contact Sid Levine, BRDE, (703) 664-5374.

Project 3796. Combat Vehicle Degassing. Magnetic signature data has been taken for the M1 and M60 tanks. Material samples have been given to the contractor. Data indicates that the approach used by the navy for ships and submarines will be valid for the land vehicles. For more information, contact Sid Levine, BRDE, (703) 664-5374.